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DEVELOPMENT OF STATEWIDE PORTLAND CEMENT PATCHING PRODUCTS AND PROCEDURES

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

MASTER OF SCIENCE

(Civil Engineering)

By

Robert L. Bartlow Jr.
Norman, Oklahoma
2000

DEVELOPMENT OF STATEWIDE PORTLAND CEMENT PATCHING

PRODUCTS AND PROCEDURES

A THESIS

APPROVED FOR THE DEPARTMENT OF CIVIL ENGINEERING

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Abstract

An investigation was performed to develop concrete mixtures capable of developing high early strength combined with relatively low shrinkage characteristics, good bonding characteristics and generally good compatibility with existing substrate and surrounding media. These concrete mixtures are intended for patching of portland cement rigid pavement and bridge decks.

This investigation consists of two parts, an Investigation in the field and an investigation in the laboratory. The field investigation consisted of testing a material that ODOT was using in 1997 to understand the state of the art in Oklahoma and to have a base line for comparison. Some experiments were conducted in the field.

The laboratory investigation involved varying the mix proportions with different combinations of accelerator and superplasticizer in the mix design and assessing their material characteristics. Type I and Type III portland cements were investigated along with concrete made with fiber as an admixture. Five promising proprietary patch mixes were also tested in this investigation. At the completion of the laboratory investigation the most promising mix design was evaluated in a full-scale field trial.

Based on results from the experimental program, mixture designs are recommended for patching concrete pavement. This Thesis also highlights prominent differences between the recommended material and a portland cement material in commercial use.

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CHAPTER 1 INTRODUCTION

1.1 PROBLEM STATEMENT

Field division maintenance units with the Oklahoma Department of Transportation (ODOT) have experienced difficulty in achieving satisfactory performance from portland cement concrete (PCC) patching materials. The non-uniformity of patch materials among ODOT field divisions has made it difficult to pinpoint the sources of unacceptable performance and led to a lack of consistency regarding what materials are considered acceptable. Research was needed to identify materials and procedures that can be reliably used by field divisions for roadway and bridge applications, and help to ensure satisfactory performance. While proprietary materials were to be evaluated for this research, emphasis was placed on the development of mixture proportions for a portland cement concrete patching material that made use of constituent materials readily available in the state of Oklahoma. The purpose of this research is to develop a concrete patching material suitable for patching in the state of Oklahoma and to develop guidelines for the proper installation of patching materials for rigid pavements and bridge decks.

1.2 SCOPE OF WORK

The research for this thesis contained several components. The scope of work generally followed the following outline.

1. A brief review of past research on this project and an evaluation of the materials developed by Chris Ramseyer (1999). A brief review of the pertinent

literature as well as past research work done on this project was included in this research program.

2. Evaluation of varying cement sources other than Holnam Type III in the portland cement concrete patching material.

3. The development of new mixture proportions accounting for the change in cement supply. The evaluation of other cement sources highlighted performance shortcomings with the patching material when cements other than Holnam Type III were used. When Holnam ceased production of its Type III cement, it became necessary to develop mixture proportions that optimized the performance of the concrete patching material when utilizing other cement sources.

4. Testing and evaluation of portland cement blended with High Aluminate Content (HAC) cement and its effects on early compressive strength when used in the proposed patching material. Several batches of patching material were cast with HAC cement blended with type I portland cement. A proprietary material named Fastpatch marketed by Burke as a "high aluminate content concrete repair material" provided the HAC cement for this research.

5. Testing and evaluation of Shrinkage Reducing Admixtures (SRA's) when added to the proposed patching material. Two proprietary SRA's were obtained for this portion of the research. Grace Construction Products® provided Eclipse SRA and Masterbuilders® provided Tetragard SRA. These admixtures are advertised to reduce drying shrinkage in the concrete by reducing the surface tension of pore water trapped within the concrete (Balogh 1996). Research focused on developing a dosage

rate that would optimize the use of the SRA's. The effect of the SRA's on compressive strength and on shrinkage were evaluated for this project.

6. Testing and evaluation of alternate admixtures in the proposed patching material. The proposed patching material in its base form makes use of two proprietary chemical admixtures. One admixture is a High Range Water Reducer (HRWR) and the other is a concrete accelerator. The admixtures used in the development of the patching material were provided by Grace Construction Products® with ADVA Cast being the HRWR and DCI Corrosion Inhibitor being the accelerator. As part of this project, other brands of admixtures were to be evaluated for use in the patching material. Sika® provided the accelerator Sika Rapid –1 and the HRWR Sikament 10 ESL. These admixtures were provided based our request for admixtures that would resemble as closely as possible the performance characteristics of the materials provided by Grace®. These admixtures were then added in similar proportions to the patching material and evaluated.

7. Testing and evaluation of polypropylene fiber reinforced patching material. This portion of the research dealt with the addition of polypropylene fibers to the proposed patching material. The purpose for adding fibers would be to increase the durability of the patching material as well as its bond characteristics. Fibermesh provided half-inch polypropylene fibers for evaluation.

8. Documentation of involvement of OU research personnel in field installation of patch materials. Beginning in August of 1999, OU research personnel were involved in consulting with ODOT and Gilbert Central Construction Contractors on a

patching project being conducted on the I-40 cross-town elevated expressway. Recommendations were made at that time regarding patching material mix proportions as well as methods for placement and evaluation of patching materials.

9. Evaluation of the field installations employing OU recommended patching materials. Beginning in August of 1999, field installations of the OU recommended patching material were made during the I-40 cross-town elevated expressway patching project. The materials made in the field were evaluated based on compressive strength at the opening of the pavement to traffic as well as visual inspections made 1 day and 6 months after placement.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

A review of pertinent literature was completed for this project. A significant portion of this literature review deals with the identification of the characteristics critical to the success of a patching material. These characteristics can be identified as: 1) Strength, 2) Compatability, 3) Durability, 4) Adhesion/Bond.

2.2 STRENGTH

A successful patch must restore the structural integrity of the concrete pavement, therefore the minimum required strength of the patch is governed by the strength of the substrate (Rizzo and Sobelman 1989). Once the concrete patch has attained this minimum strength, any additional strength attained by the patch serves little purpose. In other words it is not possible for a patched pavement to exceed the strength of the concrete substrate at the patch location.

2.3 COMPATIBILITY

Emmons et.al. (1993) divided the compatibility of the concrete patch with the existing pavement into four categories: 1) Dimensional Compatibility, 2) Chemical Compatibility, 3) Electrochemical Compatibility and 4) Permeability Compatiblity.

2.3.1 Dimensional Compatibility

Drying shrinkage could be considered the most significant factor contributing to patch failures caused by dimensional compatibility. Some studies have identified drying shrinkage as the leading cause of bridge deck cracking (Ramey et al 1999).

Drying shrinkage can occur when capillary pores within concrete lose moisture inducing a hydrostatic tension on the rigid Calcium Silicate Hydrate (CSH) skeleton causing the cement paste to shrink (Mindness and Young 1981).

If one considers that the existing concrete substrate has attained a stable drying volume, then any additional shrinkage experienced by a patch is differential shrinkage. This differential shrinkage induces tensile stresses in the patch and compressive stresses in the substrate which result in shear stresses along the patch/substrate interface. If the tensile stresses in the patch caused by differential shrinkage exceed the tensile capacity of the patch then transverse shrinkage cracks will appear in the patch. These cracks can and will ultimately contribute to the failure of that particular patch (Emmons et al 1993). Similarly, if the shear stresses induced along the interface of the patch and the substrate exceed the bond strength of the patch, then the patch will delaminate from the substrate thereby causing a failure in the patch.

Additional dimensional compatibility problems can appear because of large differences between the patch and substrate elastic moduli. If one material is significantly stiffer than the other, then the stiffer material will resist larger stresses than the less stiff material. This could result in the overloading of the stiffer material and either a failure in the stiffer material or along the bond between the patch and substrate.

2.3.2 Chemical and Electrochemical Compatibility

When a patch material encapsulates reinforcing steel, the chemical compatibility between the patch material and the substrate must be considered. There can be large differences between the chloride contents or the pH's between the two materials. Either of these chemical differences may be sufficient to develop cathode/anode regions along the reinforcing steel. These regions could initiate corrosion cells along the concrete/rebar interface (Emmons et al 1993). However, the time required for these corrosion cells to have a significant impact on the pavement normally exceeds the life of the patch that contains them.

2.3.3 Permeability Compatibility

More recent experience has discovered that problems can arise when repairs are made with low permeability materials. In fact, lower permeability in the repair material may result in greater distress to the concrete repair. In some cases, low permeability patches were found to accelerate corrosion of reinforcing steels by concentrating corrosion cells to restricted areas (Cusson 1996).

Additionally, low permeability repair materials have been blamed for the eventual failure of concrete repairs on bridge columns (Emmons et al 1994). In an unrepaired concrete member, free moisture within the concrete substrate can precipitate (due to temperature changes) and migrate to the surface of the concrete where it is free to evaporate or run off. And as the free moisture migrates through the concrete, it carries water-soluble minerals, which are then deposited on the concrete surface. However, if a concrete substrate has been covered with a layer of low

permeability repair material, then free moisture can be trapped underneath the repair. If the moisture freezes, then damage can be inflicted at the substrate-repair interface. Additionally, if the water does not freeze but evaporates, the water borne minerals will be deposited at the underside surface of the repair. Either of these conditions can cause severe damage to the patch and eventual failure.

2.4 DURABILITY

The durability of a concrete repair can be traced to the material's permeability and freeze/thaw resistance (Russell et al 1996). A low permeability is generally thought of as a positive characteristic for concrete with regards to durability. A concrete repair with a low permeability is better able to resist the infiltration of water and water inside a pavement generally serves to break down the pavement from the inside. Additionally, a material's freeze/thaw resistance is an important factor in determining that material's durability. Regardless of a material's permeability, some water will be present in the repair. When this water freezes it can serve to destroy the concrete from the inside. Therefore, categorizing a material's ability to resist freezing and thawing should be a part of determining its acceptability as a patching material.

2.5 ADHESION/BOND

A satisfactory bond between the patch material and the substrate is an essential characteristic in evaluating the acceptability of a patch material. A strong bond is important so that the inevitable stresses that develop along the patch/substrate interface do not cause a delamination of the patch material.

The literature seems to suggest that the inclusion of fiber reinforcement can produce desirable properties in a repair material. Improved bond between the patch and substrate has been on of the benefits attributed to the addition of fibers (Chanvillard et al. 1989). By bridging shrinkage-induced micro-cracks, fibers serve to reduce drying shrinkage and thus shear stresses at the interface, in some cases up to 40% (Chen et al 1995).

Additionally, the substrate surface must be properly prepared to achieve an acceptable repair (Silwerbrand et al. 1997). This preparation should include the development of soundness and roughness on the substrate surface. Some common techniques for preparing a substrate for patching include sand-, shot-,and airblasting, milling, diamond grinding, and hydrodemolition. A number of studies have concluded that abrasive techniques such as milling and pneumatic hammering can introduce micro-cracks into the substrate. The bruised section that result beneath the interface thus creates a plane of weakness (Austin et al 1996). Based on this information, these abrasive techniques should be followed by hydrodemolition or sandblasting to remove any unsound material along the substrate surface. Following this removal of material, the substrate should be washed thoroughly to remove excess material and to moisten the substrate (Silverbrand et al. 1997). This should be followed by treatment with compressed air or vacuuming to remove any excess material and water.

2.6 FIBER REINFORCED CONCRETE

There is evidence in the literature that reinforcing concrete repair materials with synthetic fibers can aid in the performance of concrete repairs. When small diameter, uniformally distributed fibers are used in concrete, it appears that the inherent tensile strength and strain of the concrete is enhanced (Shah 1990). Additionally, overlays on a Pennsylvania Interstate were cast with fiber reinforced concrete in the left-hand lane and concrete with no fiber reinforcement on the right hand lane. After six years, the lane with fiber reinforcement exhibited a better overall appearance, less cracking and appreciably less wear than the lane without fibers. Additionally, the lane without fibers exhibited severe delamination in some sections while the lane with fibers exhibited no regions of delamination (Schupack and Stanley 1992). Therefore, it would seem that a case could be made for the addition of fiber reinforcement in concrete repair materials.

2.7 PREVIOUS RESEARCH

The development of the proposed patching material began with the work completed by Chris Ramseyer in 1999. This work resulted in the development of concrete mixture proportions that produced a material suitable for the patching of rigid pavements in Oklahoma. It also produced an evaluation of several proprietary concrete repair materials. Table 2.1 lists the mixture proportions developed in 1999.

Table 2.1 Mixture Proportions for Proposed Patching Material (Ramseyer 1999)

Cement	lb/yd^3	600
Coarse Aggregate	lb/yd^3	1773
Fine Aggregate	lb/yd^3	1412
Water	lb/yd^3	210
w/c		0.35
HRWR (ADVA Cast)	oz/cwt	15
Accelerator (DCI)	oz/cwt	128

This material made use of a type III cement manufactured by Holnam in Midlothian, Texas. Unfortunately, production of this cement ceased in 1999. The need for this research project arose because of the inability of other commercially available cements to produce a material suitable for patching when used in the proportions developed by Chris Ramseyer.

Seveal proprietary patching products were tested for their acceptability as patching materials. Most failed to meet all the criteria previously mentioned for use on Oklahoma pavements. For this project, the following proprietary patching products were evaluated.

Table 2.2 Proprietary Pavement Repair Materials and Observations (Ramseyer 1999)

Material	Observation
Burke 928	Fibrous – Sticky with poor finishing characteristics – Poor Consolidation with very rapid set
Duracal	Workable but sticky. Very fast set.
Emaco T 415	Very fast set
Emaco T 430	Very fast set
Set 45	Approximately 10 minute working time and followed by almost immediate set.
Phoscrete	Material becomes very hot and sets up in 10 minutes

The rapid set characteristic of these proprietary patching products leaves little room for error during field implementation. This observation coupled with other concerns such as compatibility with the existing pavement seems to indicate that these products fall short in supplying ODOT with a satisfactory material for patching.

CHAPTER 3 TESTING PROGRAM

3.1 INTRODUCTION

The laboratory testing program was implemented to evaluate the various materials, mixture proportions, and techniques used for patching rigid pavements. Tests were performed to ascertain fresh concrete properties as well as hardened concrete properties at various ages. This chapter discusses the criteria used for testing a patch, the testing procedures as well as mixture proportions tested in the laboratory.

3.2 CRITERIA FOR PATCH MATERIAL

Before work could begin on developing a patching material, criteria for evaluating a suitable patching material for Oklahoma rigid pavements needed to be identified. After surveying ODOT personnel and reviewing pertinent literature, two hardened conrete properties and one fresh concrete property were selected as essential criteria for an acceptable patching material. These criteria were based on the compressive strength and the shrinkage of the patching material as well as its workability and finishability.

Table 3.1 Initial Criteria for Evaluating Patch Material

Compressive Strength	> 2500 psi in six hours or less
Drying Shrinkage	< 500 microstrains @ 28 days
Initial Slump	2" – 6"
Slump Life	≥ 1" @ 30 minutes

3.2.1 Compressive Strength

Early compressive strength was required because many roadways that require patching have a high traffic volume. Therefore, it is necessary to minimize the amount of time the roadway is out of service for repair. 2500 psi is the minimum compressive strength ODOT requires a patching material to attain before a patch can be open to traffic.

3.2.2 Shrinkage

The shrinkage criterion was added because many of the past patching failures in Oklahoma have been attributed to excess shrinkage. To determine a value for limiting the shrinkage of the concrete patching material, a mechanistic analysis for predicting shrinkage induced tensile stresses was coducted. This analysis was based on the stress strain model for a linear elastic material.

$$\varepsilon_{su} = f'_t \div E_{eff}$$

where:

f'_t = tensile stress of the concrete (psi)

E_{eff} = effective modulus of elasticity of the concrete (ksi)

ε_{su} = ultimate shrinkage strain of the concrete (in/in)

Two equations are commonly used to predict the tensile capacity of concrete using the compressive strength. The two equations are:

$$f'_t = 0.1f'_c \text{ and}$$

$$f'_t = 4\sqrt{f'_c}$$

where:

f'_c = concrete compressive strength (psi)

Prior research experience with portland cement concrete (PCC) patching materials indicated that a compressive strength of around 10,000 psi could be expected at 28 days. This would result in a predicted range of tensile strengths of 950 to 390 psi. For the purpose of determining a shrinkage limit for the patching material, a tensile strength of 700 psi was used.

For concrete under load, the equation for effective modulus of elasticity is as follows:

$$Eeff = E \div (1 + C_r)$$

where:

E = Secant Modulus of Elasticity (ksi)

C_r = Creep Coefficient

The creep coefficient for our material was assumed to be 3 because of the loading of the patches at early ages. The secant modulus of elasticity was predicted using the following equation:

$$E \cong 33 \times w^{1.5} \times \sqrt{f'_c}$$

where:

E = secant modulus of elasticity

w = unit weight of concrete (lb/ft^3)

With an estimated unit weight of the concrete of 150 lb/ft^3, and an estimated compressive strength at 28 days of 10,000 psi, the predicted modulus would be

approximately 6000 ksi. The resulting effective modulus would be 1500 ksi. With an effective modulus of 1500 ksi and a tensile capacity of 700 psi, the maximum tensile strain before cracking would be predicted to be 470 microstrains (10^{-6} in/in) at 28 days. This analysis led to the maximum 28-day shrinkage criterion of 500 microstrains.

The development of this shrinkage criterion depends on many assumptions and does not take into account the rate of shrinkage of the concrete. However, it does provide a parameter by which shrinkage can be constrained during the development of the patching material.

3.2.3 Slump and Slump Life

The slump and slump life criteria were developed for two reasons. First, to allow the PCC patching material time to be placed before it loses workability and second to allow time for the PCC patching material to be properly finished before setting up.

3.3 LABORATORY BATCHING AND CURING PROCEDURES

Laboratory batch procedures followed ASTM C 192, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." Concrete produced in the laboratory was mixed using a portable 6 cubic foot, electric power driven revolving drum mixer. A typical batch began with moistening the inside of the mixer as well as any tools being used. This not only aided in keeping the equipment clean but also minimized any moisture from being removed from the concrete by absorption. The mixer was charged by adding aggregates first, then half of the water,

followed by the cement, then any admixtures and ending with the remaining water. If any fibers were added to the mix, they were added after all other materials had been added to the batch.

After batching, the concrete was then placed in the appropriate specimen molds to cure. All specimens for this project were cured under insulation for six hours. This was done in order to prevent heat loss during hydration and to increase the temperature of the concrete as it cured in order to speed the rate of hydration. This practice is also utilized in the field, therefore applying it in the lab allows for better correlation between materials made in the field and in the lab. All curing took place inside an environmental chamber maintained at 73.4° F and 50% relative humidity. After six hours, the insulation was removed and the concrete was then cured in the open air inside the environmental chamber.

3.4 TESTS – FRESH CONCRETE PROPERTIES

Table 3.2 lists the fresh concrete tests performed along with the corresponding ASTM designation. All tests were performed in conformance with the ASTM specification unless otherwise noted.

Table 3.2 Fresh Concrete Tests Performed

Test	ASTM Number
Slump	C 143
Fresh Concrete Temperature	C 1064
Unit Weight	C 138
Air Content	C 231
Slump Loss with Time	C 143

3.4.1 Slump

The slump test not only provides an indication of the workability of fresh concrete but it can also be a useful quality control tool. Slump tests were performed in conformance with ASTM C 143 and values were recorded for all batches in this testing program.

3.4.2 Temperature

Fresh Concrete Temperature was measured for every batch in this testing program in conformance with ASTM C 1064. Temperature was recorded immediately after mixing using a standard concrete thermometer.

3.4.3 Unit Weight

A unit weight test was performed for every concrete batch in the laboratory in conformance with ASTM C 138. This test was utilized primarily as a quality control measure. Once the unit weight of fresh concrete was determined, it was checked against the theoretical unit weight of the concrete calculated prior to batching. Large differences between the theoretical and actual unit weights indicate a possible error in the proportioning of the concrete mixture.

3.4.4 Air Content

The air content test was performed for most concrete batches in this testing program in conformance with ASTM C 231. The air meter used in laboratory testing conformed to "Meter type B" as mentioned in ASTM C 231, and no aggregate correction factor was used. Since no air entraining agents were utilized in this testing program, this test was used to measure entrapped air in the concrete.

3.4.5 Slump Loss with Time

The Slump Loss Over Time test was performed on the final patching material. For this test, slump values were recorded immediately after mixing and at five minute intervals thereafter until a "0" slump value was recorded or 30 minutes had passed.

3.5 TESTS – HARDENED CONCRETE PROPERTIES

Table 3.3 lists all hardened concrete property tests performed during this laboratory investigation. All tests were performed in conformance with the applicable ASTM standards.

Table 3.3 Tests for Determining Hardened Concrete Properties

Test	ASTM Number
Compressive Strength	C 39
Unrestrained Length Change	C 490
Bond Strength (Shear Cylinder)	C 882
Bond Strength (Shear Beam)	N/A
Modulus of Elasticity	C 469
Tensile (Split Cylinder) Strength	C 496
Tensile (MOR) Strength	C 78
Ion Permeability	C 1202
Freeze/Thaw	C 666

3.5.1 Compressive Strength

The Compressive Strength tests were performed for each concrete batch in this testing program. Compressive strength specimens were made by placing fresh concrete into 4" x 8" plastic cylinder molds in conformance with ASTM C 192. Compressive strengths were then tested in conformance with ASTM C 39. Unbonded caps were used during the testing of compressive cylinders as specified in ASTM C 1232. The compressive strength for each cylinder tested is presented as a stress

calculated by dividing the maximum load sustained by the cylinder divided by the cylinder's cross-sectional area (12.57 in^2). All compressive strength tests were performed in a Forney®, LC-1 concrete testing machine.

3.5.2 Unrestrained Length Change

The unrestrained length change of concrete was used as a measurement of the drying shrinkage a sample undergoes during a specific period of time. The unrestrained length change was measured in conformance with ASTM C 490 except in the curing of the specimens. The specimens utilized for this test were fabricated by placing fresh concrete into 4"x 4"x10" steel forms. Set-screws were embedded in the concrete at either end of each form. All measurements were made using a comparitor and a reference bar. The comparitor was fitted with a dial gauge capable of 10^{-5} inch readings. The reference bar was used before and after each specimen measurement to check for consistency in the measurements. Typically, prisms were removed from molds after 4 hours and initial readings were made. Specimens were stored dry in an environmental chamber maintained at 75 deg. F and 50% relative humidity. Readings were then made at 6, 9, 12, 24, hours as well as 7 and 28 days.

3.5.3 Bond Strength – Shear Cylinder

The Shear Cylinder test is a modified version of ASTM C 882, "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear." For this test, cores were taken from concrete pavement substrate specimens. The Oklahoma Department of Transportation provided these substrate specimens as a representative sample of the existing concrete infrastructure in the

state. The specimens came from U.S. 69 near Eufala in McIntosh County, Oklahoma, and are approximately 30 years old. The substrate material had a compressive strength of 6650 psi and an elastic modulus of 2,300,000 psi.

The substrate specimens for this test were cut in half at a 45° angle. Prior to batching the patching material, the half cores were placed in a standard 4"x8" plastic cylinder mold. The patching concrete was then placed in the molds containing the specimens. The result was a concrete cylinder containing a concrete substrate and a patching material bonded along a plane inclined at an angle of 45°.

The degree of bond was determined by subjecting the bonded cylinder to a standard compressive strength test in accordance with ASTM C 39. The bond strength was calculated as the compressive force that produced a failure of the bond divided by the elliptical bond area measured as 17.24 square inches. When a test specimen failed in compression it became impossible to determine the exact bond strength of the patch. In these instances, only the minimum bond strength could be determined. Typically, bond strength was tested at 1 day and 28 days.

3.5.4 Bond Strength – Shear Beam

The second bond strength test in the testing program was the shear beam bond test. For this test, concrete substrates were cast using a standard ODOT pavement mix. The substrates were 5 feet long, 14 inches wide, and 3 inches deep. After they had cured, the surfaces of the substrates were prepared by sandblasting. Prior to batching the patch material, the substrates were cleaned of all loose material and moistened. The patch material was then placed on the substrates creating a 3.5-inch

patch along the entire surface of the substrate. The result was a concrete beam consisting of 3-inch substrate material bonded to a 3.5 inch thick patch material overlay. Each substrate was cast around two #4 grade 60 ksi reinforcing bars for a total steel area of 0.4 in^2. After testing the first beam, an additional 0.75 in^2 of steel was bonded to the bottom of the remaining beams in the form of one 3/8"x 2"x 5' steel plate. This additional steel brought the total steel area to 1.15 in^2. This test attempted to ascertain the bond strength for a specimen by inducing a horizontal shear failure in a beam along the patch/substrate interface.

3.5.5 Modulus of Elasticity

The modulus of elasticity is the ratio of normal stress to normal strain in a defined area of a material's elastic range. The secant modulus of this range is generally accepted as the modulus of elasticity. The modulus of elasticity test for the concrete patching material was performed in conformance with ASTM C 469. The test was performed on standard 4"x 8" concrete cylinders. The cylinders were fitted with an external, electronic extensiometer to measure deformations during loading.

3.5.6 Tensile Strength – Splitting Cylinder

The splitting cylinder method for determining the tensile strength of concrete was performed in conformance with ASTM C 496 using a compressive testing machine. 4"x 8" concrete cylinders were used for this test.

3.5.7 Tensile Strength – Modulus of Rupture (MOR)

The modulus of rupture method for determining the tensile strength of concrete was performed in conformance with ASTM C 78. Test specimens were cast

by placing fresh concrete into 6" x 6" x 18" steel forms. Specimens were then tested using the third point loading method in a compressive testing machine. After failure, measurements were taken along the failure plane in order to determine the cross-sectional area. This area along with the failure load was then used to determine the modulus of rupture for the concrete.

3.5.8 Ion Permeability

The Rapid Chloride Ion Permeability (RCIP) test was performed in conformance with ASTM C 1202. This test gives an indication as to a material's ability to resist the penetration of chloride ions. This resistance to chloride ion penetration can then be correlated to the permeability of the concrete. Automatic data processing equipment was utilized to calculate the coulomb value for each test. Tests were typically run on specimens at 56 days.

3.5.9 Resistance to Freezing and Thawing

The concrete's ability to resist the effects of freezing and thawing was tested in conformance with ASTM C 666. Testing prisms were cast by placing fresh concrete into steel forms. The prisms were placed in trays filled with water in a freeze/thaw testing machine. Longitudinal and transverse dynamic modulus values were recorded for each specimen prior to testing, at 100 and at 300 testing cycles. These measurements as well as specimen size and weight were used to develop the durability factors for the concrete.

3.6 LABORATORY TESTING PROGRAM

The laboratory testing program involved batching patching materials with various mixture proportions and evaluating them through testing. All materials listed in this section were developed and tested at Fears Structural Engineering Lab at the University of Oklahoma.

Note: All references to coarse aggregate in this thesis refer to #67 crushed limestone supplied by Dolese Brothers Concrete unless other wise noted. All references to fine aggregate in this thesis refer to a washed river sand called Dover Sand supplied by Dolese Brothers Concrete unless otherwise noted.

3.6.1 Development of Mix Proportions with Various Cement Sources

This project began with the evaluation of cements other than Holnam Type III in the proportions provided by Chris Ramseyer. The chemical properties of the three cements along with Holnam Type III are listed in Table 3.4.

Table 3.4 Cement Chemistry and Fineness Values

	Ashgrove Type III (%)	Holnam Type III (%)	Lonestar Type III (%)	Holnam Type I (%)
Chemical Compositions				
SiO_2	20.56	19.70	20.06	20.3
Al_2O_3	4.74	5.80	5.45	6.00
Fe_2O_3	3.06	2.76	2.38	2.6
CaO	64.10	61.40	64.07	64.6
MgO	2.49	0.90	1.57	0.97
SO_3	3.14	4.15	3.77	3.21
Compound Compositions				
C_3S	63.00	57.10	57.6	55.8
C_2S	12.00	13.80	10.43	15.9
C_3A	6.00	10.50	*	11.25
C_4AF	9.00	*	*	*
Blaine Air Fineness	4740	5240	4480	3310

One batch was produced for each cement source evaluated. The mix proportions for each batch are listed in Table 3.5.

Table 3.5 Mixture Proportions for Batches Evaluating Other Cement Sources

Cement Type		Type III	Type III	Type I
Cement Provider		Ashgrove	Lonestar	Holnam
Batch Number		**#1**	**#2**	**#3**
Cement	lb/yd^3	600	600	600
Coarse Aggregate	lb/yd^3	1773	1773	1773
Fine Aggregate	lb/yd^3	1412	1412	1412
Water	lb/yd^3	210	210	210
w/c		0.35	0.35	0.35
HRWR (ADVA Cast)	oz/cwt	15	15	15
Accelerator (DCI)	oz/cwt	128	128	128

Each batch was tested for fresh concrete properties immediately after mixing. Additionally concrete cylinders were cast for testing at 4, 6, 9, 12, 24 hours as well as 7 and 28 days.

The mixture proportions for the proposed patching material were altered for the next round of tests. These batches had increased cement content, from 600 lb/yd^3 to 700 lb/yd^3. All other proportions were left unchanged. Table 3.6 lists the mixture proportions for the batches with increased cement content.

Table 3.6 Mixture Proportions for Batches with Increased Cement Content

Cement Type		Type I	Type III
Cement Provider		Holnam	Lonestar
Batch Number		**#4**	**#5**
Cement Content	lb/yd^3	700	700
Coarse Aggregate	lb/yd^3	1787	1787
Fine Aggregate	lb/yd^3	1337	1337
w/c		0.3	0.3
HRWR (ADVA Cas	oz/cwt	13	13
Accelerator (DCI)	oz/cwt	110	110

Testing for these batches included fresh concrete properties as well as compressive strengths taken at 4, 6, 9, 12, 24 hours and 7 and 28 days.

The next round of tests was conducted on duplicates of batches 4 and 5. Theses two batches had cement contents of 700 lb/yd^3 and were made with Holnam Type I cement and Lonestar Type III cement respectively. Six batches were cast in order to complete more thorough testing of the patching material. The mixture proportions of these batches are listed in Table 3.7.

Table 3.7 Mixture Proportions of Batches with Increased Cement Contents

Cement Type		Type I	Type III
Cement Provider		Holnam	Lonestar
Batch Number		**6,8,10**	**7,9,11**
Cement Content	lb/yd^3	700	700
Coarse Aggregate	lb/yd^3	1787	1787
Fine Aggregate	lb/yd^3	1337	1337
w/c		0.3	0.3
HRWR (ADVA Cast)	oz/cwt	13	13
Accelerator (DCI)	oz/cwt	110	110

Batches 6 and 7 were cast for testing compressive strength, drying shrinkage, and RCIP. Batches 8 and 9 were cast for testing the freeze/thaw resistance of the concrete patching material. Batches 10 and 11 were cast in order to test the slump loss with time of the patching material.

3.6.2 Batches with Portland Cement/High Aluminate Content Cement

Three batches were cast with calcium aluminate cement (CAC) blended with Type I portland cement. The portland cement used was a type I cement provided by Holnam in Midlothian, Texas. The source of CAC was the proprietary cement Fastpatch marketed by Burke as a high aluminate concrete repair material. Each batch had the same mix proportions with the only variable being the replacement percentage of CAC. Batches 12, 13, and 14 contained HAC blended with portland cement at dosages of 2%, 5%, and 3% by weight respectively. Mixture proportions for batches 12, 13, and 14 are listed in Table 3.8.

Table 3.8 Mixture Proportions for Batches with HAC/Portland Cement Blends

Cement Type		Blended	Blended	Blended
Cement Provider		Holnam/Burke	Holnam/Burke	Holnam/Burke
Batch Number		**12**	**13**	**14**
Cement Content	lb/yd^3	600	600	600
CAC	%	2	5	3
Coarse Aggregate	lb/yd^3	1787	1787	1787
Fine Aggregate	lb/yd^3	1337	1337	1337
w/c		0.35	0.35	0.35
HRWR (ADVA Cast)	oz/cwt	12.86	12.86	12.86
Accelerator (DCI)	oz/cwt	110	110	110

The purpose for blending the CAC with portland cement was to investigate its effect on the early compressive strength of the concrete patching material. Consequently, the only hardened concrete property measured for these batches was compressive strength.

3.6.3 Optimizing Accelerator Dosage

Batches 15, 16, and 17 were cast to determine the optimum dosage rate of accelerator. The accelerator used for this portion of the research was DCI Corrosion Inhibitor marketed by Grace Construction Chemicals®. While DCI is marketed as a corrosion inhibitor, it does possess significant accelerating characteristics (W.R. Grace® 1994). Optimizing the dosage rate of accelerator is important as the accelerator is the most expensive component of the patching material.

For this testing batch #7 with Lonestar type III cement was used as the control batch with a dosage rate of 110 ounces per hundred weight of cement (oz/cwt).

Batches 15, 16, and 17 were cast with dosages at 50%, 67%, and 83% of the control. Table 3.9 lists the mixture proportions for batches #15, #16 and #17.

Table 3.9 Mixture Proportions for Accelerator Optimization Batches

Cement Type		Type III	Type III	Type III
Cement Provider		Lonestar	Lonestar	Lonestar
Batch Number		**15**	**16**	**17**
Cement	lb/yd^3	700	700	700
Coarse Aggregate	lb/yd^3	1787	1787	1787
Fine Aggregate	lb/yd^3	1337	1337	1337
Water	lb/yd^3	128.5	121.9	115.3
w/c		0.35	0.35	0.35
HRWR (ADVA Cast)	oz/cwt	12.86	12.86	12.86
Accelerator (DCI)	oz/cwt	55	73	91

Because accelerator directly effects the compressive strength gain of concrete, these batches were evaluated based on early compressive strength. Compressive strength tests were performed for these batches at 4, 6, 9, 12, 24 hours as well as 7 and 28 days.

3.6.4 Addition of Shrinkage Reducing Admixtures

Batches 18 through 23 were cast to investigate the effect adding of shrinkage reducing admixtures would have on the drying shrinkage of the patching material. Two mixture proportions used for this testing, one for Type I cement and the other for Type III cement. The mix proportions used were those provided by Chris Ramseyer as this research was conducted while Holnam Type III cement was still commercially available. Two shrinkage reducing admixtures (SRA's) were used for this investigation: Eclipse manufactured by Grace Construction Products® and Tetragard provided by Masterbuilders®. The SRA's were dosed by percentages of the cement

weight as suggested by the manufacturer. Table 3.10 lists the mixture proportions for the type III cement batches made with SRA's added.

Table 3.10 Mixture Proportions for Type III Cement Batches with SRA's Added

Cement Type		Type III	Type III	Type III	Type III
SRA Bramd		None	Tetragard	Eclipse	Tetragard
Cement Provider		Holnam	Holnam	Holnam	Holnam
Batch Number		**18**	**19**	**20**	**21**
Cement	lb/yd^3	600	600	600	600
Shrinkage Reducer	%	0	2^{*}	2^{+}	1^{*}
Coarse Aggregate	lb/yd^3	1773	1773	1773	1773
Fine Aggregate	lb/yd^3	1412	1412	1412	1412
Water	lb/yd^3	210	210	210	210
w/c		0.35	0.35	0.35	0.35
HRWR (ADVA Cast)	oz/cwt	15	15	15	15
Accelerator (DCI)	oz/cwt	128	128	128	128

Batch 18 was a control batch cast for this portion of the research. Batches 19 and 20 were cast with Eclipse and Tetragard added at 2% of the cement respectively. Batch 21 was cast with 1% Tetragard added. Two type I cement batches were cast, batch 22 with 2% Tetragard and batch 23 with 2% Eclipse added. Table 3.11 lists the mixture proportions for batches 22 and 23.

Table 3.11 Mixture Proportions for Type I Cement Batches with SRA's Added

Cement Type		Type I	Type I
SRA Brand		Tetragard	Eclipse
Cement Provider		Holnam	Holnam
Batch Number		**22**	**23**
Cement	lb/yd³	600	600
Shrinkage Reducer	%	2*	2⁺
Coarse Aggregate	lb/yd³	1773	1773
Fine Aggregate	lb/yd³	1443	1443
Water	lb/yd³	198	198
w/c		0.33	0.33
HRWR (ADVA Cast)	oz/cwt	10	10
Accelerator (DCI)	oz/cwt	128	128

3.6.5 Evaluating Other Brands of Admixtures

This portion of the research dealt with evaluating a HRWR and an accelerator from a source other than Grace Construction Products®. Sika® supplied a HRWR, Sikament, and an accelerator, Sika Rapid-1, that matched as closely as possible the products provided by Grace®. Batches 24 and 25 were made with the admixtures provided by Sika®. In Batch 24, the admixtures are added at the same proportions considered optimum for the Grace® products. Batch 25 has the amount of HRWR doubled and the accelerator slightly increased. Table 3.12 lists the mix proportions for batches 24 and 25. These batches were evaluated based on their compressive strength.

Table 3.12 Mix Proportions for Batches Made with Sika® Admixtures

Cement Type		Type III	Type III
Cement Provider		Lonestar	Lonestar
Batch Number		**24**	**25**
Cement Content	lb/yd^3	700	700
Coarse Aggregate	lb/yd^3	1787	1787
Fine Aggregate	lb/yd^3	1337	1337
w/c		0.3	0.3
HRWR (Sikament)	oz/cwt	12.86	26
Accelerator (Sika Rapid)	oz/cwt	110	114

3.6.6 Batches with Fibers

A total of 5 batches were cast to investigate the effect fibers would have on the patching mix. Of particular interest was the effect that the addition of fibers would have on the tensile strength and the bond strength of the proposed patching material. Batch 26 was cast as a control batch without fibers while batch 27 had fibers at 0.75 lb/yd^3 and batch 28 had fibers at 1.5 lb/yd^3. Batch 29 was cast without fibers as a control batch for the horizontal shear beams while batch 30 was cast for beams with fibers at 0.75 lb/yd^3. Table 3.13 list the mix proportions for batches made with fibers. Batches 26 through 28 were cast for making cylinders, MOR prisms, and shrinkage prisms. Batches 29 and 30 each yielded two horizontal shear beams for testing.

Table 3.13 Mixture Proportions for Batches with Fibers

Cement Type		Type III	Type III	Type III
Cement Provider		Lonestar	Lonestar	Lonestar
Batch Number		**26,29**	**27**	**28,30**
Cement Content	lb/yd^3	700	700	700
Coarse Aggregate	lb/yd^3	1787	1787	1787
Fibers	lb/yd^3	0	0.75	1.5
Fine Aggregate	lb/yd^3	1337	1337	1337
w/c		0.35	0.35	0.35
HRWR (ADVA Cas	oz/cwt	12.86	12.86	12.86
Accelerator (DCI)	oz/cwt	110	110	110

CHAPTER 4 TEST RESULTS AND DISCUSSION

4.1 INTRODCUTION

This chapter will present and discuss the results of tests conducted at Fears Structural Engineering Laboratory at the University Of Oklahoma. All compressive strength, splitting cylinder, shrinkage, and slant shear bond values are the average of three test results unless otherwise noted. All freeze/thaw, MOR, and RCIP values are the average of four test results unless otherwise noted.

4.2 DEVELOPMENT OF MIXTURE PROPORTIONS WITH CEMENT FROM VARYING SOURCES

Prior to this research project, mixture proportions were developed that produced an acceptable patching material (Ramseyer 1999). These proportions are listed in Table 4.1. These mixture proportions were developed using a type III cement manufactured by Holnam in Midlothian Texas. Early in 1999, Holnam ceased production of its type III cement, creating a need to evaluate other cement sources in the patching mixture proportions.

Table 4.1 Original Patch Material Mixture Proportions

Cement	(lb/yd^3)	600
Coarse Aggregate, #67	(lb/yd^3)	1777
Fine Aggregate, Dover Sand	(lb/yd^3)	1337
Accelerator, DCI	(oz/yd^3)	768
HRWR, ADVA®	(oz/yd^3)	90
w/c		0.35

Batch numbers 1, 2, and 3 were produced using these mixture proportions listed in table 4.1. The cements and their sources are listed in table 4.2.

Table 4.2 Cement Types and Brands, Batches 1,2, and 3

Mix Number	Cement Type	Manufacturer	Production Location
1	Type III	Ashgrove	Chanute, Kansas
2	Type III	Lonestar	Pryor, Oklahoma
3	Type I	Holnam	Midlothian, Texas

Concerns as to whether cements from other sources would produce acceptable early compressive strengths originated from other research at Fears Lab that had discovered significant differences in Blaine Air Fineness values produced different early strengths in concrete (Russell and Hale 1999). Table 4.3 lists some commercially available cements and their Blaine Fineness Values.

Table 4.3 Blaine Fineness Values of Cements

Cement	Blaine Fineness (cm^2/g)
Ash Grove, Type III, Chanute KS	4740
Holnam, Type III, Midlothian TX	5240
Lone Star Type III, Pryor OK	4480

(Russell and Hale 1999)

Typically, finer cements produce higher early compressive strengths due to increased rate of hydration over less fine cements (Mindness and Young 1981). Therefore one might expect that with a difference in fineness values of up to 750 cm^2/g, the material containing Holnam Type III cement would attain greater early compressive strengths than concrete made with the other cements. To test these concerns, these first three batches were evaluated based on their ability to achieve early compressive strength. The fresh concrete properties of batch #1,batch #2 and batch #3 are listed in table 4.4.

Figure 4.1 illustrates the early compressive strength gain of the concrete made using varying cement sources compared to concrete made with Holnam Type III cement.

Table 4.4 Fresh Concrete Properties of Patch Material with Varying Cement Sources

Cement Type		Type III	Type III	Type I
Cement Provider		Ashgrove	Lonestar	Holnam
Batch Number		**#1**	**#2**	**#3**
Slump	inches	6	9	5
Unit Weight	lb/ft^3	149.2	149.0	150.0
Batch Temperature	°F	73	65	72
Air Content	%	1.8	2.1	2

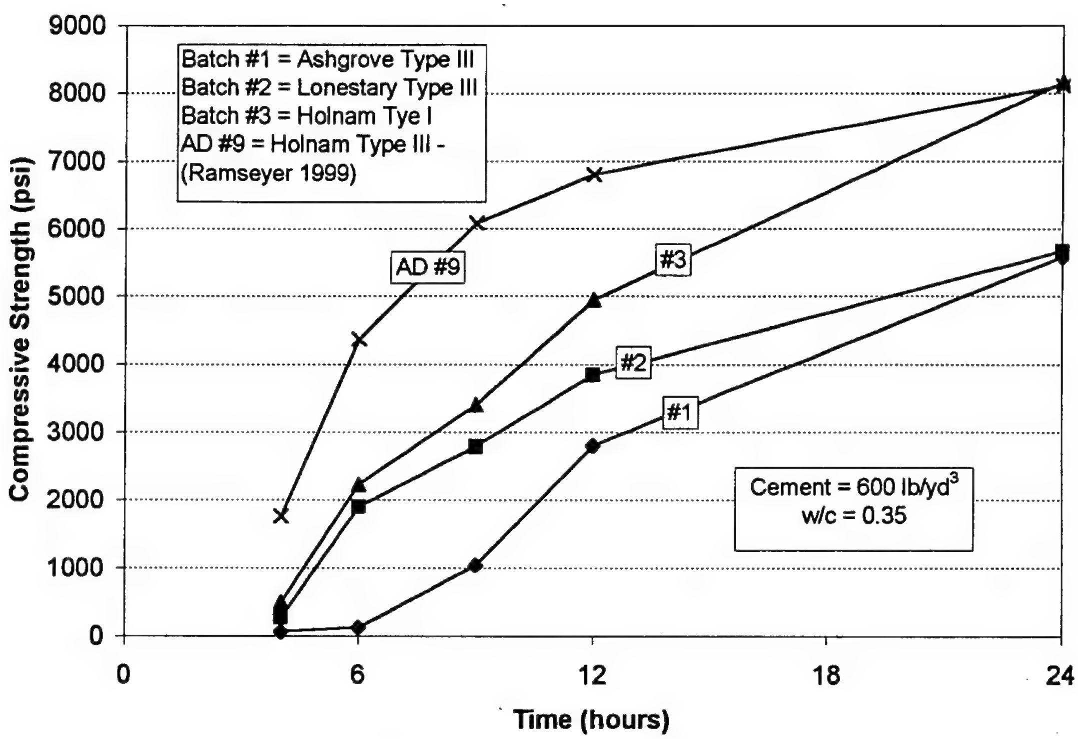

Figure 4.1 Early Compressive Strengths for Patch Material with Varying Cement Sources.

Table 4.4 indicates that batch #1, batch #2, and batch #3 achieved marginal workability characteristics, as slumps did vary between 5 and 9 inches. Each batch also failed to achieve adequate early compressive strength at 6 hours. Batch AD #9 was made with the same mixture proportions as the other batches, however it contained Holnam Type III cement (Ramseyer 1999). Referring to table 3.3 in chapter 3, no significant explanation for these results can be found in the chemical compositions of the cements. This experimental evidence indicates that differing cement fineness values can result in different early compressive strengths.

The next step in the research was to develop mixture proportions that would produce a material that would develop adequate early compressive strength. To accomplish this, two methods were employed: increasing the cement content of the patching material mixture proportions and blending the portland cement with a High Aluminate Content (HAC) Cement.

4.3 CONCRETE MADE WITH INCREASED CEMENT CONTENT

In an attempt to increase the early compressive strength gain of the patching material with other cements, the cement content of the pathcing material mixture proportions was increased from 600 lb/yd^3 to 700 lb/yd^3. All other proportions were kept constant. (note: In some cases, dosages of chemical admixtures are defined by ounces per hundred weight of cement (oz/cwt). Therefore, when the cement content changes, the value reported in oz/cwt will reflect a change in dosage even though the actual amount of admixture in the mixture proportions has remained constant. Additionally, when cement content is increased and the amount of water in the mix is

kept constant, the w/c will decrease.) Table 4.5 lists the mixture proportions of the batches made with increased cement content.

Table 4.5 Mixture Proportions for Patching Material with Increased Cement Content

Cement	(lb/yd^3)	700
w/c		0.30
Coarse Aggregate, #67	(lb/yd^3)	1787
Fine Aggregate, Dover Sand	(lb/yd^3)	1337
Accelerator, DCI	(oz/yd^3)	768
HRWR, ADVA®	(oz/yd^3)	90

Batches #4 and #5 were cast with increased cement content. Ashgrove type III cement was not tested based on its poor performance in the first round of tests. This narrowed the focus of the research to the Holnam Type I and the Lonestar Type III cements. Batch number 4 was batched using Holnam Type I cement and Batch number 5 was cast using Lonestar Type III cement. Table 4.6 lists the fresh concrete properties of Batches 4 and 5 while figure 4.2 demonstrates their 24 hour compressive strength gain. Table 4.6 demonstrates that the batches did attain adequate workability characteristics.

Table 4.6 Fresh Concrete Properties of Batches with Increased Cement Content

Cement Type		Type I	Type III
Cement Provider		Holnam	Lonestar
Batch Number		**#4**	**#5**
Slump	inches	7.5	9
Unit Weight	lb/ft^3	149.4	149.4
Batch Temperature	°F	75	78
Air Content	%	1.9	2

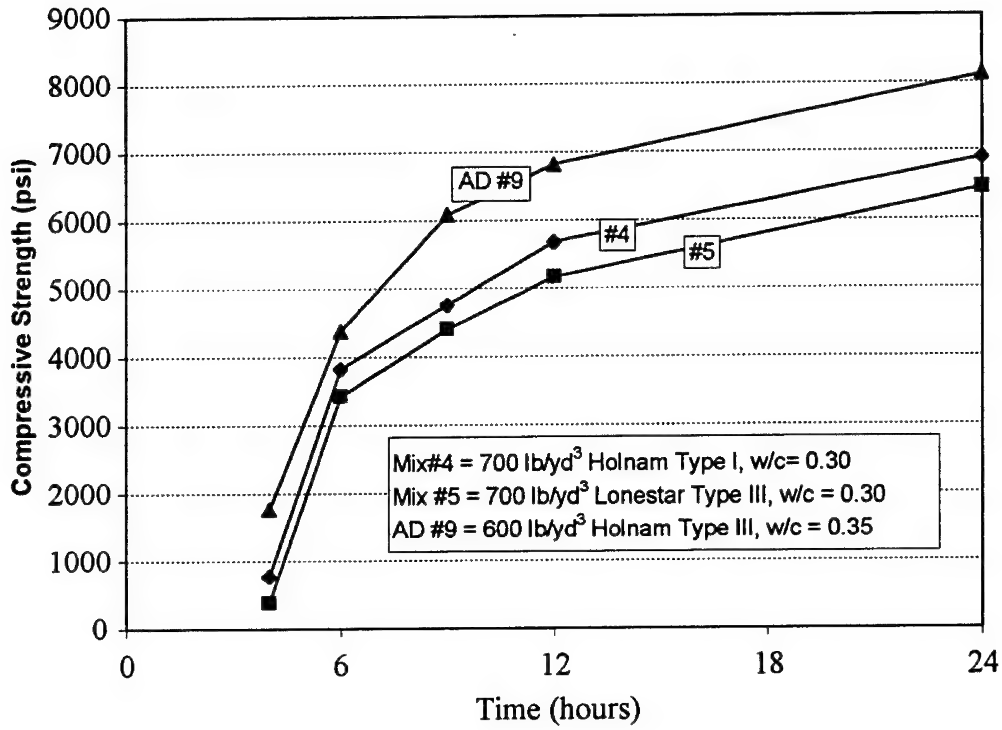

Figure 4.2 Early Compressive Strength of Concrete Made with Increased Cement Content

As Figure 4.2 demonstrates, the batches made with 700 pounds of cement per cubic yard (pcy) greater compressive strength at early ages than batches made with 600 pcy of cement. These batches also attained early compressive strength results comparable to the concrete made with the Holnam Type III mixture proportions. These batches demonstrated that by increasing the cement content, a patching material with adequate compressive strength performance could be produced using cement from alternate sources.

4.4 BATCHES WITH PORTLAND CEMENT BLENDED WITH HIGH ALUMINATE CONTENT CEMENT

Another possible method for increasing the early compressive strength gain of the patching material was to blend High Aluminate Content (HAC) cement with portland cement in small amounts. The rapid strength gain characteristics of HAC cement when blended with portland cement can be useful when used in concrete repairs (Mindness and Young 1981). Batch #12, #13, and #14, were made with HAC cement replacing with Type I portland cement provided by Holnam at percentages of 2%, 3% and 5% by weight. As a result, the cement content for these batches remained 600 pcy. The source of HAC was Burke Fastpatch, a proprietary pavement patching product. The original mixture proportions utilizing a cement content of 600 lb/yd^3 and a w/c of 0.35 were used for these batches. These batches were also evaluated based on their ability to achieve an early compressive strength of 2500 psi or greater in 6 hours or less. Table 4.7 lists the fresh concrete properties of Batch #12, #13 and #14.

Table 4.7 Fresh Concrete Properties of Batches Made with Blended Portland and HAC Cements

emet e		2 Blend	5 Blend	3 Blend
emet r er		Holnam/Burke	Holnam/Burke	Holnam/Burke
Batch Number		12	13	14
um	che			
t e ht	b t^3	14	14	14 4
Batch em erature				
r te t		2 2	2 4	2

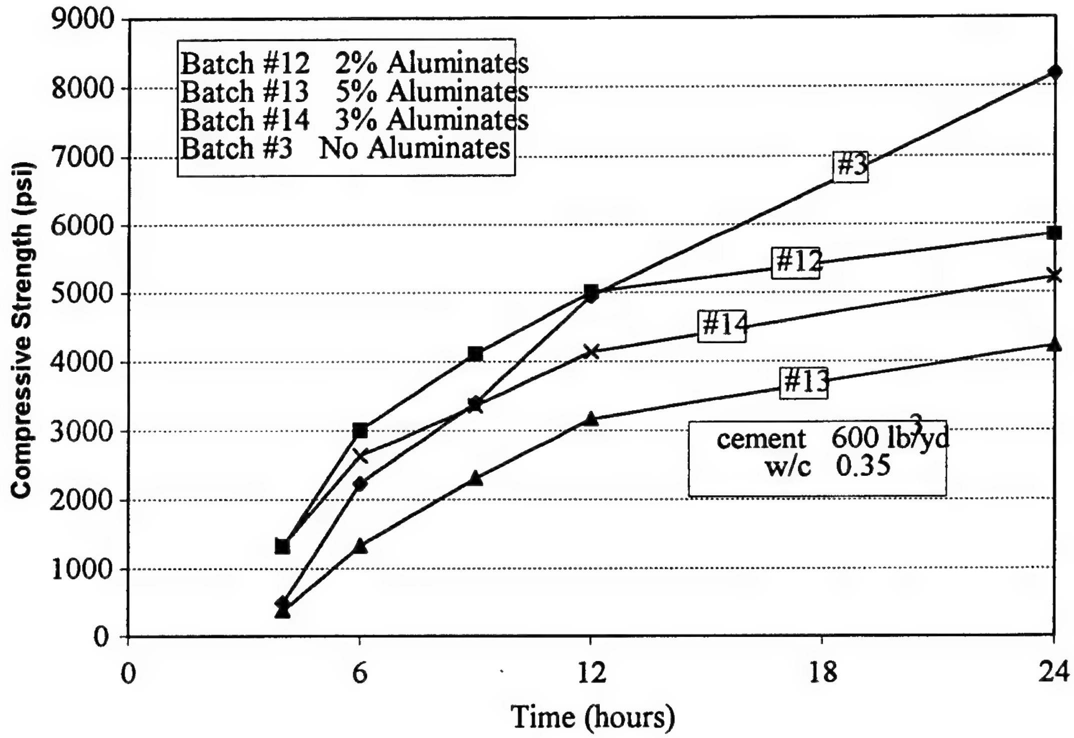

Figure 4.3 Early Compressive Strengths for Batches with HAC/Portland Cement Blends

Table 4.7 demonstrates that the mixtures with HAC/Portland cement blends achieved adequate workability. Figure 4.3 displays the 24 hour compressive strength gain of the batches with blended cements. The data does not seem to indicate any clear advantage for blending Type I portland cement and HAC. In fact, the trend that is apparent is that as HAC content increases, the early compressive strength decreases. This data eliminated blending cements as a practical option for increasing the early compressive strength of the patching material.

4.5 OPTIMIZING ACCELERATOR DOSAGE

The next step in the evaluation of the patching material was to optimize the dosage of acclerator. The logic behind this testing was that with the increase in cement content, early compressive strength values might still be attainable with less accelerator added. Three batches #15, #16, and #17 were cast using the proposed mixture proportions containing 700 lb/yd^3 cement at a w/c of 0.30. The accelerator used for this testing was DCI Corrosion Inhibitor marketed by Grace Construction Chemicals®. Dosages were tested 50%, 67% and 83% of the original dosage of 110 oz/cwt. Table 4.8 lists the fresh concrete properties for batches 15 through 17. Figure 4.4 demonstrates the 24 hour compressive strength gain of the same batches.

Table 4.8 Fresh Concrete Properties of Accelerator Dosage Optimization Batches

eme t e		Type III	Type III	Type III
eme t r er		Lonestar	Lonestar	Lonestar
Batch Number		15	16	17
um	che	5	2	2 25
t e ht	b t^3	147	14 1	14 4
Batch em erature		5	77	5
r te t			2	1 7

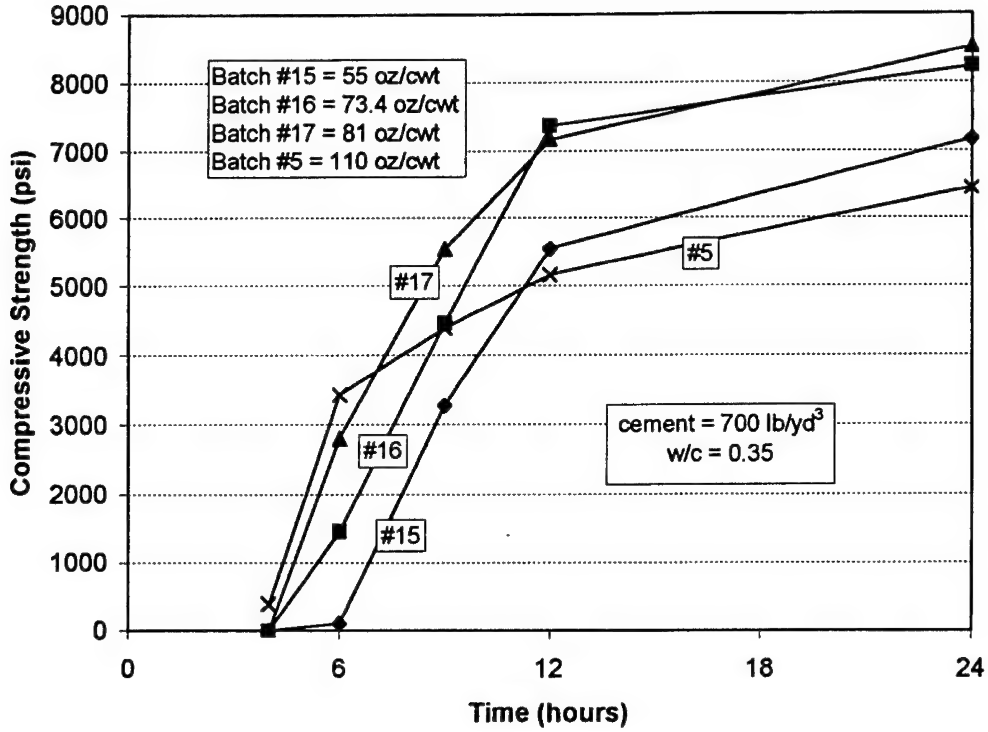

Figure 4.4 Early Compressive Strength Gain of Accelerator Dosage Optimization Batches

Table 4.9 Six Hour Compressive Strength Values for Accelerator Dosage Optimization Batches

Batch Number			15	16	17	5
cce erat r	**c t**		55	73	91	110
Compressive Stren	gth 6 hours	psi	100	1450	2800	3435

Batch #5, was included with the compressive strength data for comparison with the other batches because it contained the original accelerator dosage rate of 110 oz/cwt. When compared to the original dosage, the data demonstrates that only batch 17, with a dosage of 91 oz/cwt, attains an acceptable compressive strength at six

hours. Additionally, table 4.8 shows that batches 15 through 17 achieve only marginal workability with slumps ranging from 0.5" to 2.25". As a result, the patch mixture proportions retained the original accelerator dosage of 110 oz/cwt.

4.6 BATCHES WITH SHRINKAGE REDUCING ADMIXTURES (SRA)

Because excessive drying shrinkage can be a decisive factor contributing to the failure of concrete pavement repairs, any practical method that can be employed to reduce the shrinkage of the material should be explored. One method for reducing drying shrinkage in concrete is the addition of shrinkage reducing admixtures (SRA's). Two SRA's were evaluated for this research: Eclipse supplied by Grace Construction Chemicals® and Tetragard supplied by Masterbuilders®. Two mixture proportions used for this testing, one for Type I cement and the other for Type III cement. The mix proportions used were those provided by Chris Ramseyer as this research was conducted while Holnam Type III cement was still commercially available (the mixture proportions are available in Chapter 3 - "Testing Procedures"). Batches with SRA added were evaluated based on their shrinkage characteristics and their early compressive strength. Four type III batches, 18 – 21, were cast with varying amounts of accelerator including a control batch without accelerator. Table 4.10 lists the type III batches along with their fresh concrete properties.

Table 4.10 Fresh Concrete Properties of Type III Cement Batches with SRA

Cement Type		Type III	Type III	Type III	Type III
SRA Bramd		None	Tetragard	Eclipse	Tetragard
Cement Provider		Holnam	Holnam	Holnam	Holnam
Batch Number		18	19	20	21
hr ae e ucer	**ceme t e ht**	0	2	2	1
um	inches	3.5	9.5	4	3
t e ht	lb/ft^3	149	148.7	149.2	149.4
Batch em erature	°F	96	79	85	91
r te t	%	n/a	n/a	n/a	n/a

note: Batch 18 is control batch without any SRA added

Each batch developed adequate workability, however batch 19 did exhibit higher slump value than was expected. However, its unit weight did not seem to indicate an error in the batching proportions. The higher slump value could be partially attributed to the lower fresh concrete temperature of 79 F.

Two type I cement batches were also cast with varying amounts of SRA. Table 4.11 lists the fresh concrete properties for batches 22 and 23.

Table 4.11 Fresh Concrete Properties of Type I Cement Batches with SRA

Cement Type		Type I	Type I
SRA Brand		Tetragard	Eclipse
Cement Provider		Holnam	Holnam
Batch Number		**22**	**23**
Shrinkage Reducer	% of cement weight	2*	2^{+}
Slump	inches	7	4
Unit Weight	lb/ft^3	149.5	149.4
Batch Temperature	°F	82	93
Air Content	%	n/a	n/a

Both type I cement batches exhibited adequate fresh concrete properties. Figures 4.5 illustrates the shrinkage of the type III batches for the first 24 hours after batching.

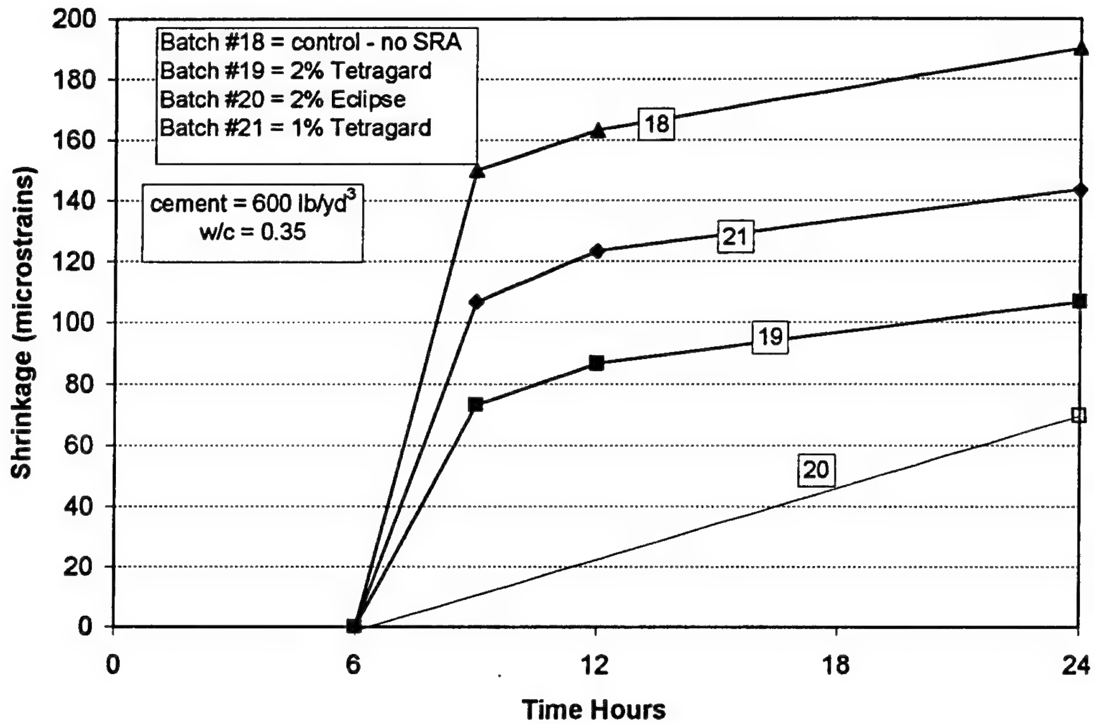

Figure 4.5 Early Shrinkage for Type III Cement Batches with SRA

The data represented in figure 4.5 indicates that the addition of SRA does in fact reduce the shrinkage of the patching concrete made with type III cement over 24 hours. Figure 4.6 illustrates the shrinkage for the same batches over 28 days.

note: Batch #20 did not set up in time for shrinkage specimens to be tested at 9 or 12 hours.

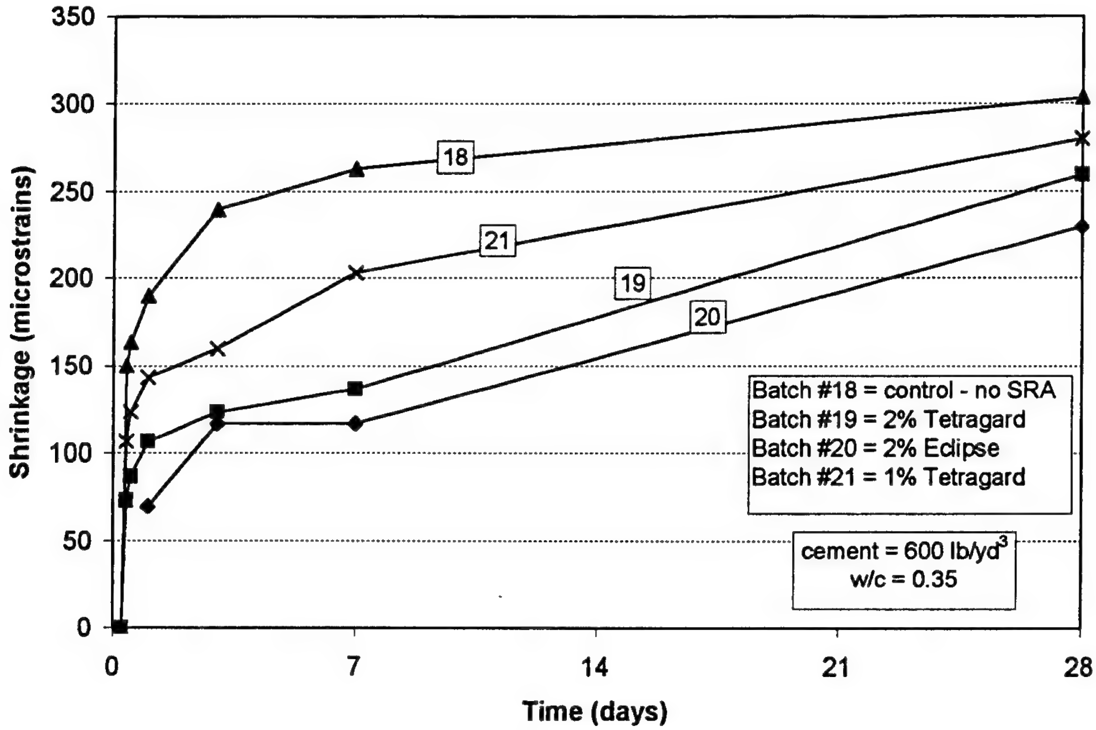

Figure 4.6 28 Day Shrinkage for Type III Cement Batches with SRA

Figure 4.6 points out that while at 28 days, the batches with SRA continue to exhibit lower shrinkage values than those without SRA, those differences seem to have remained constant. At 24 hours, the approximate difference between the batch with the most shrinkage and the batch with the least shrinkage was 80 microstrains. At 28 days, the approximate difference was 85 microstrains. This indicates that the SRA's have most of their effect on the shrinkage that occurs within the first 24 hours after the batching of the concrete.

The data for type I batches also indicates that SRA's do aid in reducing the shrinkage of the concrete as is demonstrated in figure 4.7.

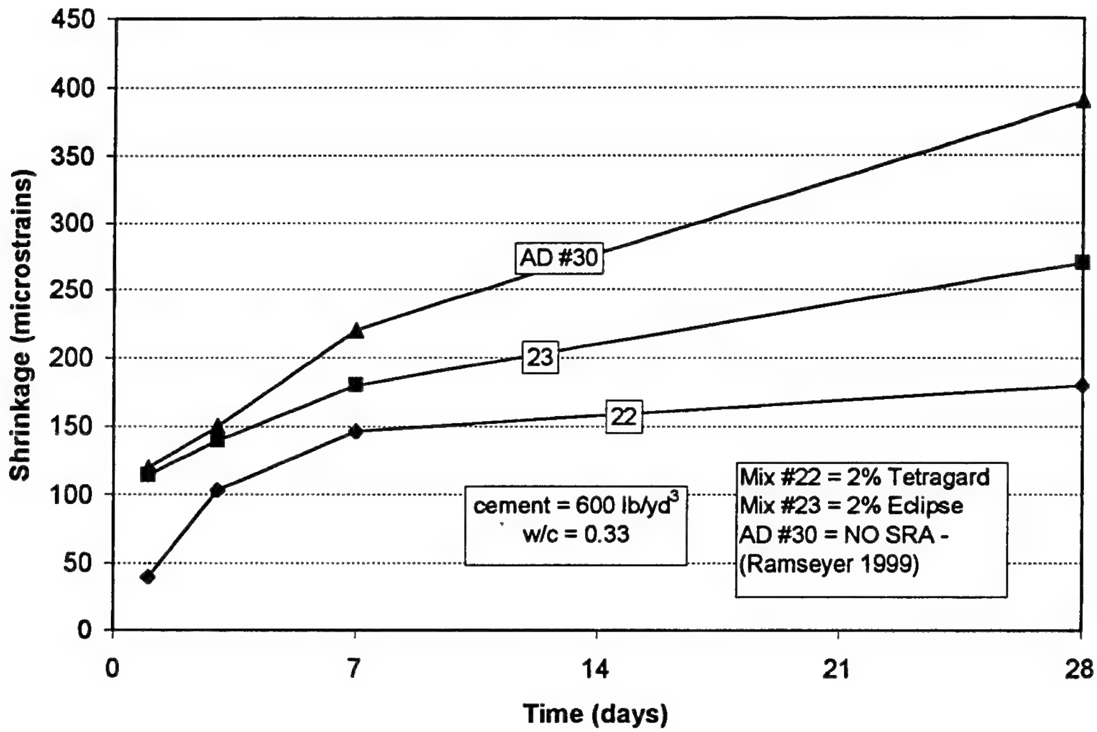

Figure 4.7 28 Day Shrinkage for Type I Cement Batches with SRA

For figure 4.7, data from batch AD #30 (Ramseyer 1999), was added as a comparison batch without SRA added.

The batches with SRA were also evaluated based on compressive strength. Figure 4.8 illustrates the 24 hours compressive strength gain of type III cement batches made with SRA.

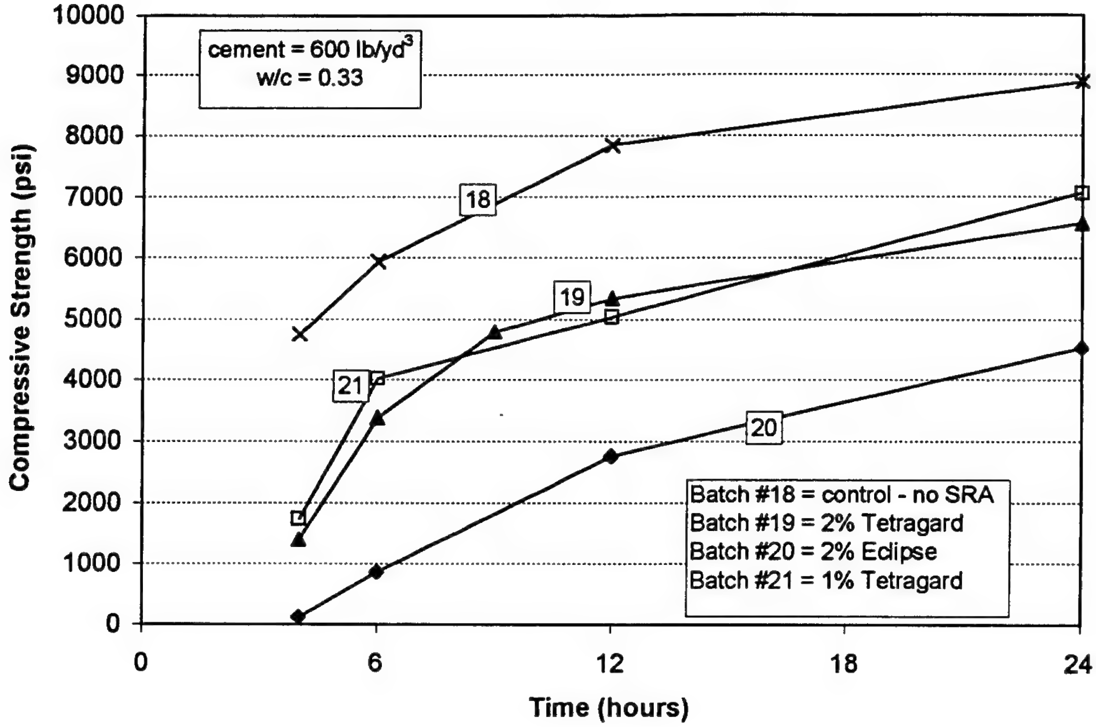

Figure 4.8 Early Compressive Strength for Type III Cement Batches with SRA

The compressive strength data demonstrates that the addition of SRA does reduce the compressive strength of the patching material over 24 hours when compared to material without SRA added. However, the compressive strengths of the patching material batched with Tetragard SRA still exceeds the requirement of 2500 psi at 6 hours. Figure 4.9 also illustrates reduced compressive strength values for type I batches with SRA added.

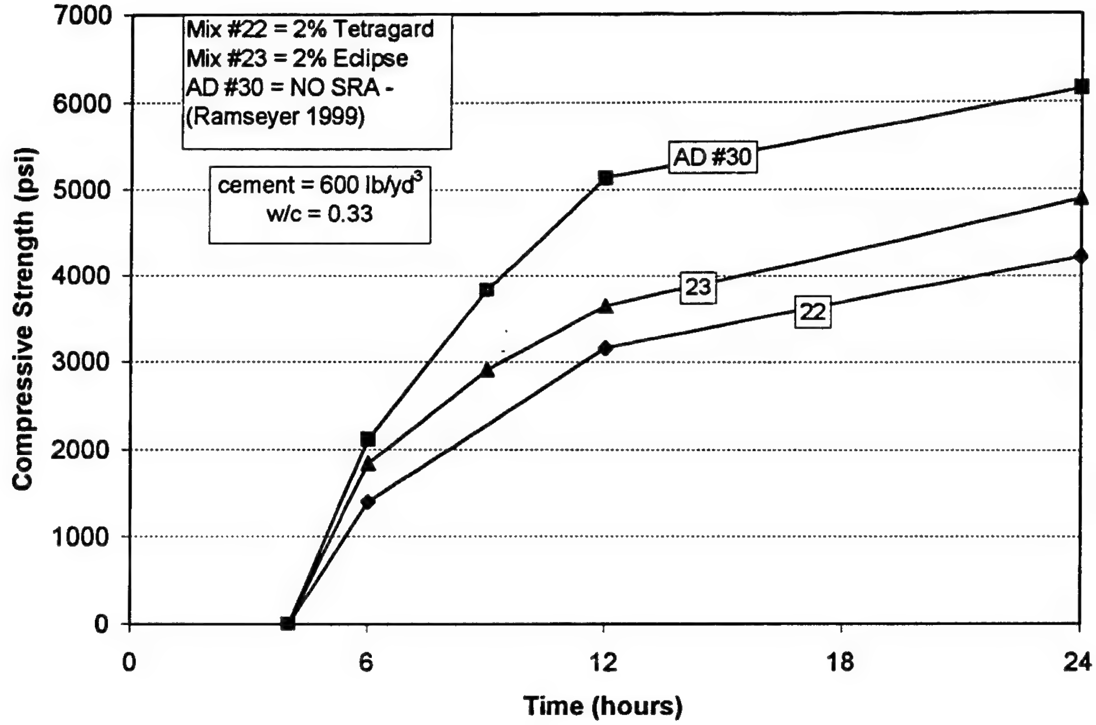

Figure 4.9 Early Compressive Strength for Type I Batches with SRA

Again, batch AD #30 (Ramseyer 1999) has been added to the type I cement data for the purpose of comparing SRA batches to a batch with the same mix proportions without SRA.

The data indicates that it is possible to add SRA to the proposed patching material and reduce the shrinkage without reducing the early compressive strength below acceptable levels. However, shrinkage values for the patching material without SRA all fall below the shrinkage limit of 500 microstrains at 28 days. This fact coupled with the significant reductions in early compressive strength for batches with SRA led to the decision not to include SRA's in the proposed patching material mixture proportions.

4.7 Evaluating Other Brands of Admixtures

In order to evaluate an admixture brand other than Grace Construction Products®, a High Range Water Reducer (HRWR) and a hardening accelerator were obtained from the Sika Corporation®. The HRWR provided by Sika® was Sikament-10ESL and the accelerator was Sika Rapid-1. These admixtures were provided by Sika® based on our request to obtain admixtures that would most closely resemble those provided by Grace Construction Chemicals®. The purpose for this evaluation was to ascertain whether other admixtures introduced at the same or similar dosages as the originals would produce a patching material with similar performance characteristics. The primary concern was the effect different admixtures would have on the early compressive strength gain of the patching material. Table 4.12 lists the fresh concrete properties for batches 24 and 25 made with Sika® products.

Table 4.12 Fresh Concrete Properties of Batches with Sika® Admixtures

Cement Type		Type III	Type III
Cement Provider		Lonestar	Lonestar
Batch Number		**24**	**25**
Slump	inches	n/a	5
Unit Weight	lb/ft^3	n/a	148.9
Batch Temperature	^oF	n/a	78
Air Content	%	n/a	1.3

Batch #24 was mixed with the Sika® accelerator and HRWR dosed at the exact levels as the Grace® admixtures. This batch remained extremely dry and rocky with no apparent free moisture. The batch was abandoned after allowing it to

continue to mix in the mixer for approximately 10 minutes with no apparent improvement. The next batch was mixed with twice the original dosage of HRWR based on the recommendation of another graduate assistant who had some experience with Sika® admixtures. The resulting mix, batch #25, did achieve acceptable workability with 5 inches of slump. However, as figure 5.10 illustrates, the compressive strength of batch #25 falls far short of the required 2500 psi at six hours.

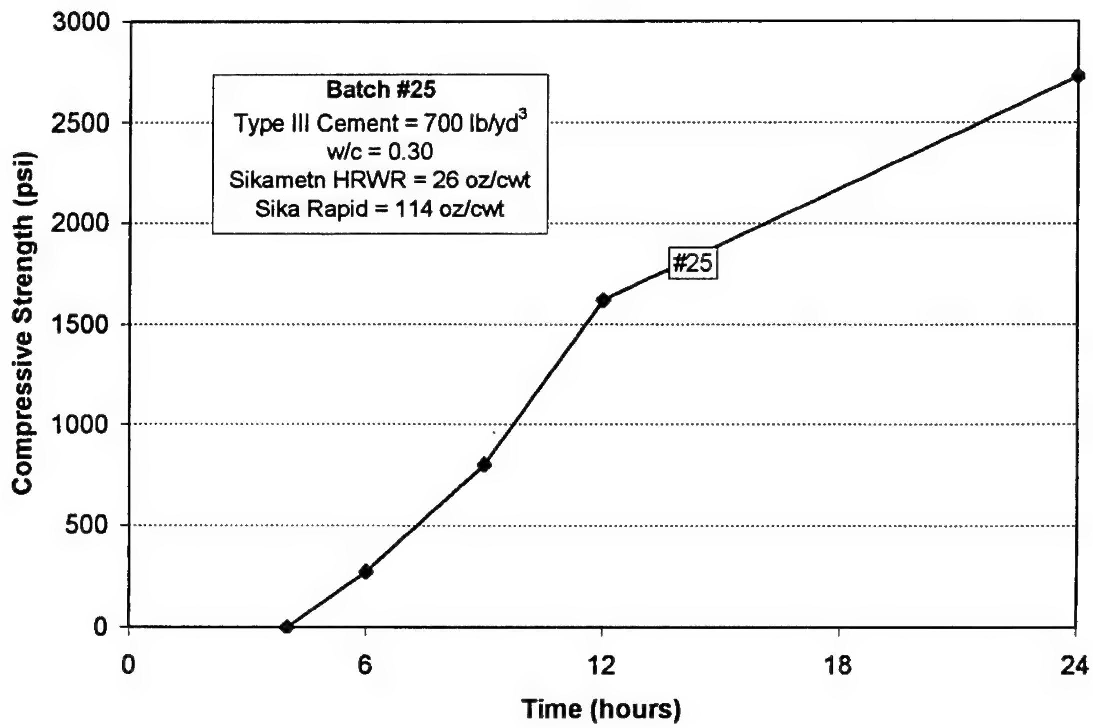

Figure 4.10 Early Compressive Strength of Batch with Sika® Admixtures

As a result of this testing, it was concluded that while it may be possible to achieve acceptable performance from a patching material utilizing various admixture sources, it would be difficult to develop mixture proportions that would be uniform for all brands of admixtures.

4.8 FURTHER EVALUATION OF PATCHING MATERIAL

In order to make a recommendation regarding patching material mixture proportions, testing beyond fresh concrete properties and compressive strength was required. Table 4.13 list the batches along with the mixture proportions selected for evaluation.

Table 4.13 Mixture Proportions for Proposed Patching Material

Cement Type		Type I	Type III
Cement Provider		Holnam	Lonestar
Batch Number		**6,8,10**	**7,9,11**
Cement Content	lb/yd^3	700	700
Coarse Aggregate	lb/yd^3	1787	1787
Fine Aggregate	lb/yd^3	1337	1337
w/c		0.3	0.3
HRWR (ADVA Cast)	oz/cwt	13	13
Accelerator (DCI)	oz/cwt	110	110

Two mixture proportions were selected for final evaluation, one for type I cement and the other for type III cement. As it turned out, both proportions were identical except for the cement type. Three batches were needed for each mixture proportion in order to prepare an adequate number of specimens for testing. The first two batches, #6 and #7, of each mix proportion were used for testing compressive strength, drying shrinkage and RCIP. Table 4.14 lists the fresh concrete properties for batches 6 and 7.

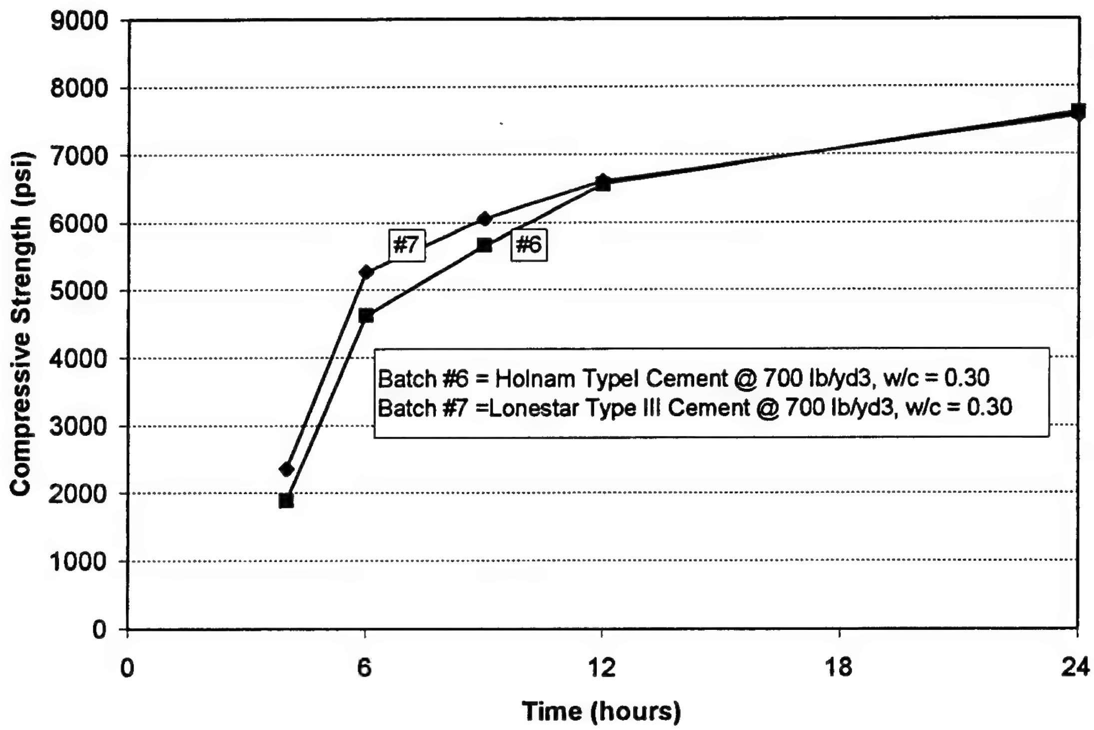

Figure 4.11 Early Compressive Strength of Proposed Patching Mixtures

Table 4.14 Fresh Concrete Properties for Proposed Patching Material, Batches 6 and 7

Cement Type			Type I	Type III
Cement Provider			Holnam	Lonestar
Batch Number			**6**	**7**
Slump	Fresh	inches	9	6.75
Unit Weight		lb/ft^3	149.2	149.4
Batch Temperature		^{o}F	73	90
Air Content		%	2.1	1.9

Table 4.14 indicates that the batches 6 and 7 achieved adequate workability. Figure 4.11 illustrates the 24 hours compressive strength of the proposed patching material. The data presented in Figure 4.11 demonstrates that batches made with both mixture proportions achieve compressive strengths at 6 hours much greater than the required 2500 psi.

Figure 4.12 illustrates the 58 day shrinkage for batches 6 and 7. This data demonstrates that both mixture proportions exhibit a lower shrinkage at 28 days than the maximum allowable 500 microstrains.

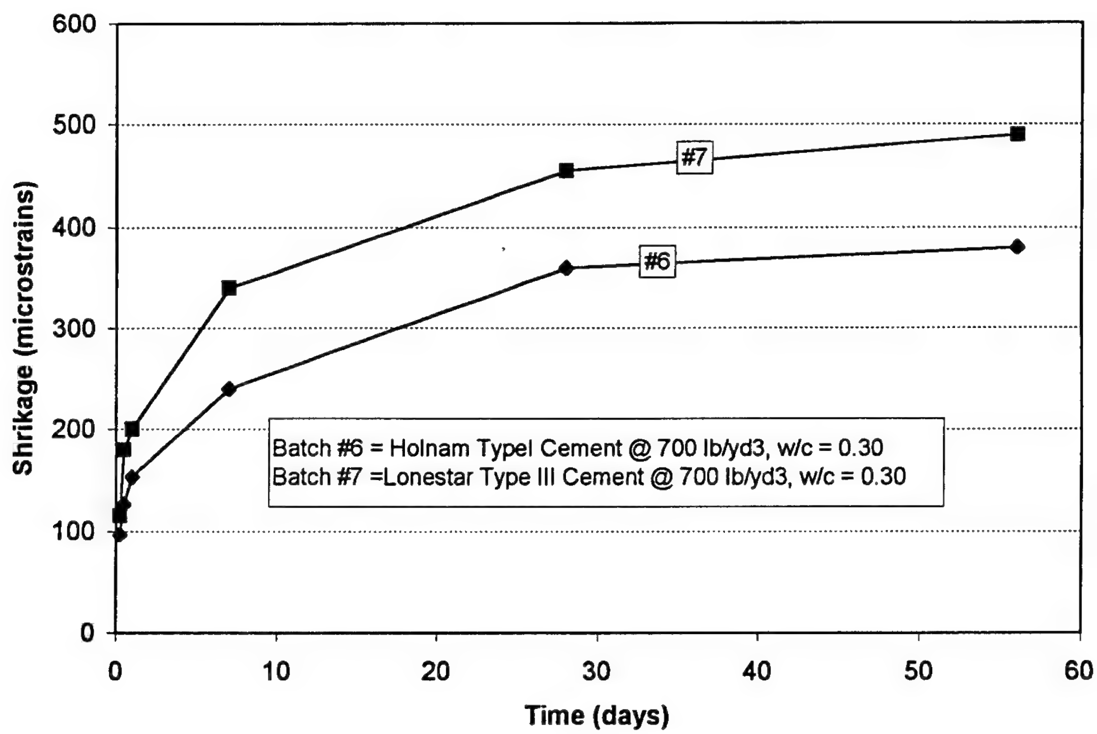

Figure 4.12 56 Day Shrinkage for Proposed Patch Material Mixture Proportions

Table 4.15 lists the Rapid Chloride Ion Permeability (RCIP) values for both mixture proportions.

Table 4.15 RCIP Values for Proposed Patch Material

Cement Type	Type I	Type III
Cement Provider	Holnam	Lonestar
Batch Number	**6**	**7**
Coulombs passed	1295	978
Permeability - ASTM C 1202	low	very low

According to the results from the RCIP test, the permeability of the proposed patching mixture proportions would be categorized as low to very low. Developing a low permeability patching material was not an objective of this research project. In fact, the literature suggests that there can be some negative side effects to patching with a low permeability material. However, the fact that these materials exhibit low permeability characteristics was not considered reason enough to abandon their recommendation for use in the field.

Batches 8 and 9 were cast at the same mixture proportions as 6 and 7, however they were used to produce freeze/thaw specimens. Table 4.16 lists the fresh concrete properties of batches 8 and 9.

Table 4.16 Fresh Concrete Properties for Proposed Patching Material, Freeze/Thaw Batches

Cement Type			Type I	Type III
Cement Provider			Holnam	Lonestar
Batch Number			**8**	**9**
Slump	Fresh	inches	6.25	5
Unit Weight		lb/ft^3	148.7	150.1
Batch Temperature		^oF	75	80
Air Content		%	2.1	1.8

Batches 8 and 9 exhibited similar fresh concrete properties to batches 6 and 7, which aids in demonstrating the repeatability of the material. Table 4.17 lists the 6 hour and 28 day compressive strength values for batches 8 and 9.

Table 4.17 Compressive Strength Values for Freeze/Thaw Batches

Cement Type			Type I	Type III
Cement Provider			Holnam	Lonestar
Batch Number			**8**	**9**
Compressive Strength	6 hours	psi	3770	5375
	28 day	psi	10090	10150

The freeze/thaw batches exhibited adequate compressive strength gain values that were similar in performance to previous batches with the same mix proportions. Table 4.18 lists the durability factors for batches 8 and 9 obtained after 300 continuous freeze/thaw cycles.

Table 4.18 Durability Factors for Freeze/Thaw Batches

Cement Type	Type I	Type III
Cement Provider	Holnam	Lonestar
Batch Number	**8**	**9**
Durability Factor ASTM C 666	94	75

These durability factors could be considered higher than what might be expected with a material that does not contain air entrainment. These values, though, could be a result of the low permeability of the patching material.

The final evaluation of these mixture proportions included determining their slump loss with time. Figure 4.16 illustrates the slump loss for the proposed mixture proportions.

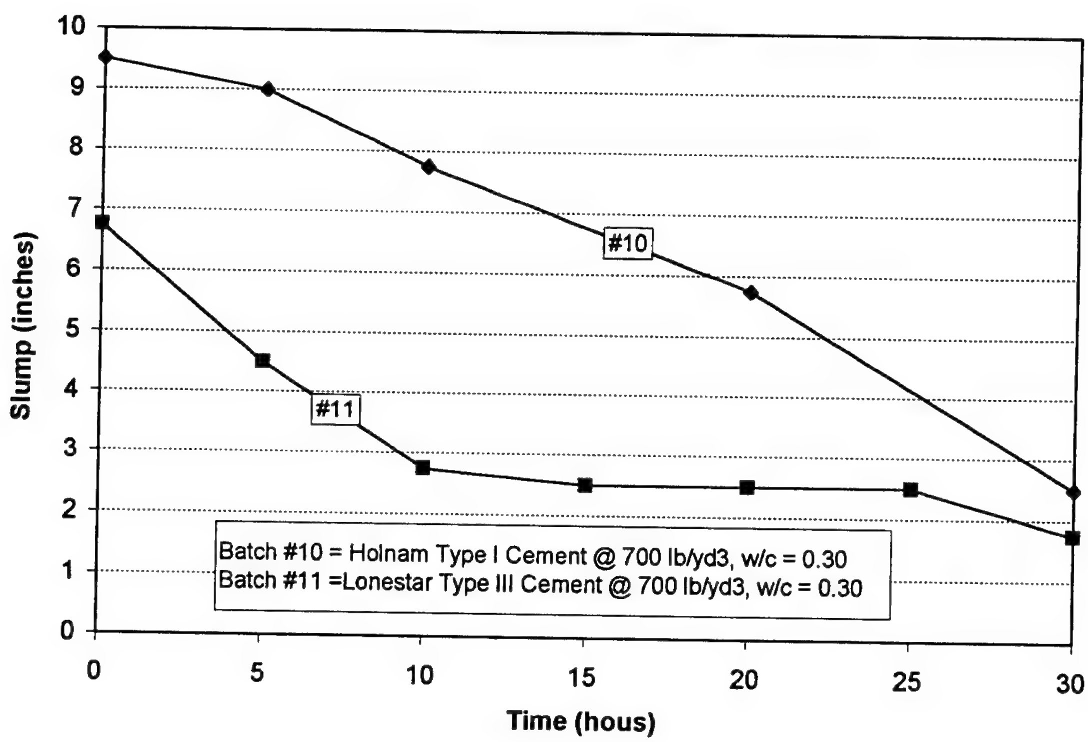

Figure 4.13 Slump Loss Values for Proposed Patch Material

Both the type I mixture proportion and the type III mixture proportion retained enough workability at 30 minutes to exhibit slumps of greater than one inch. It should be noted that these materials were kept in a wheel barrow during testing. If the material were to be continually mixed over the same period of time, workability could probably be maintained for a longer period.

The evaluation of the proposed mixture proportions demonstrates that the proposed patching material is reproducible in the laboratory. In addition, further testing of the material did not highlight any further problems with permeability, shrinkage, freeze-thaw resistance or slump over time. The recommendation that would result from this laboratory research would be that these mixture proportions were ready for evaluation in the field.

4.9 AIR ENTRAINMENT

An evaluation of air entrainment in the patching material was not conducted in the laboratory. However, some that may wish to utilize these mixture proportions in the field may also want to add air entrainment for the purpose of long term freeze/thaw resistance. Several arguments can be made for not adding air entriament to these particular mixture proportions. First of all, there it is likely that incorporating air entrainment in the patching mixture may result in varying, inconsistent slumps, unit weights, air contents and strength performance. Secondly, the life span requirement for many patches is 10 years or less, thereby precluding the need for the long-term freeze/thaw resistance provided by air entrainment. Lastly, the freeze/thaw durability testing conducted on the material indicates that it possesses adequate

freeze/thaw resistance. Therefore, air entrainment in considered optional for this material.

4.10 BATCHES WITH FIBERS

The final portion of this laboratory investigation dealt with the addition of polypropylene fibers to the final proposed patching mixture proportions. Fibers were added at two dosage rates and compared to a control batch made without any fiber reinforcement. Fibers were added to the type III cement mixing proportion for this portion of the research. Fiber batches were evaluated based on compressive strength, tensile strength, shrinkage and bond performance. The dosage rates for the fibers are presented in table 4.19.

Table 4.19 Polypropylene Fiber Dosage Rates for Patching Material

Cement Type		Type III	Type III	Type III
Cement Provider		Lonestar	Lonestar	Lonestar
Batch Number		**26,29**	**27,30**	**28**
Fibers	lb/yd^3	0	0.75	1.5

Batches 26 – 28 were used to produce compressive strength, shrinkage, MOR, and slant-shear testing specimens. Batches 29 and 30 were used to make horizontal shear beams.

Table 4.20 lists the fresh concrete fibers for batches 26 – 28.

Table 4.20 Fresh Concrete Properties for Batches with Fibers

Cement Type		Type III	Type III	Type III
Cement Provider		Lonestar	Lonestar	Lonestar
Batch Number		**26**	**27**	**28**
Fibers	lb/yd^3	0	0.75	1.5
Slump	inches	5	4.5	4
Unit Weight	lb/ft^3	149.8	150.3	150.1
Batch Temperature	°F	76	76	78
Air Content	%	2.1	1.8	1.9

The slump values for the batches with fibers exhibited a slight decrease, however, the workability of the batches with fibers remained good. Figure 4.17 demonstrates the compressive strength gain of the batches with fibers.

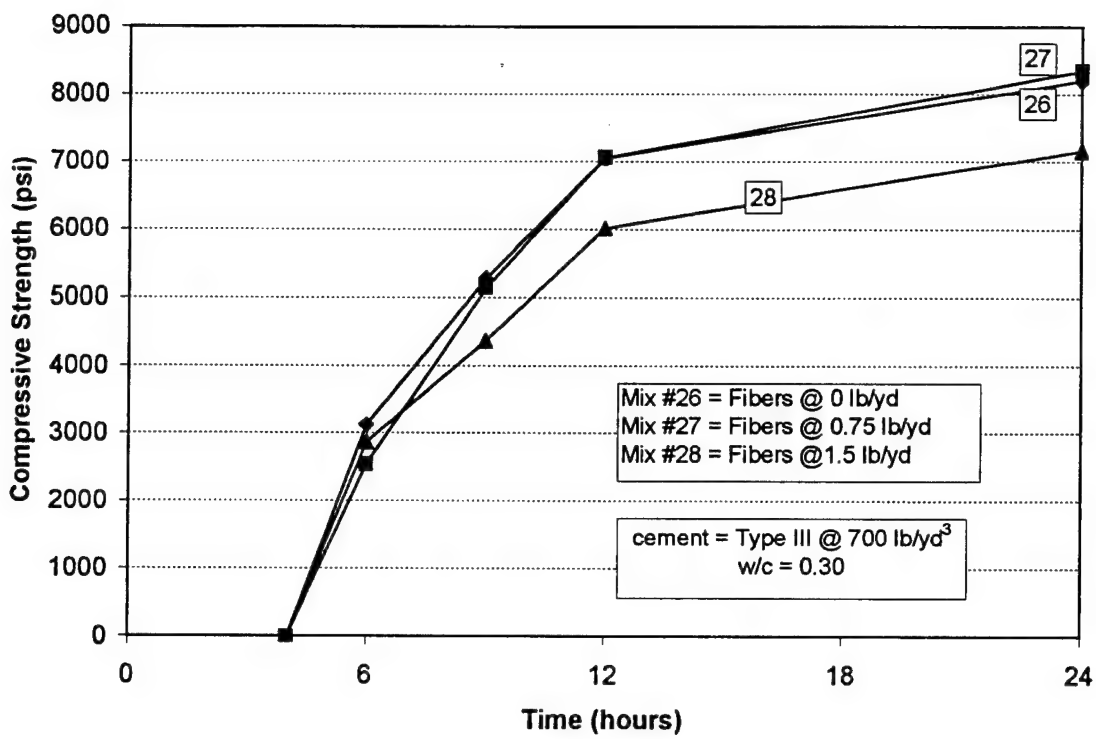

Figure 4.14 Early Compressive Strength of Batches with Fibers

Figure 4.17 demonstrates that batches with fibers did exhibit adequate compressive strength at six hours. The batches with fibers did have slightly less compressive strength at six hours, however the differences are all within 500 psi. The lower overall compressive strengths of these batches at six hours compared with other batches could be attributed to the concrete temperature being close to 70 degrees for all batches. Additionally, these batches were cast in the late winter with ambient temperatures below 60 degrees while most other batches in this research program were cast during the heat of the summer. In any case, the batches with fibers still attained acceptable compressive strengths at six hours.

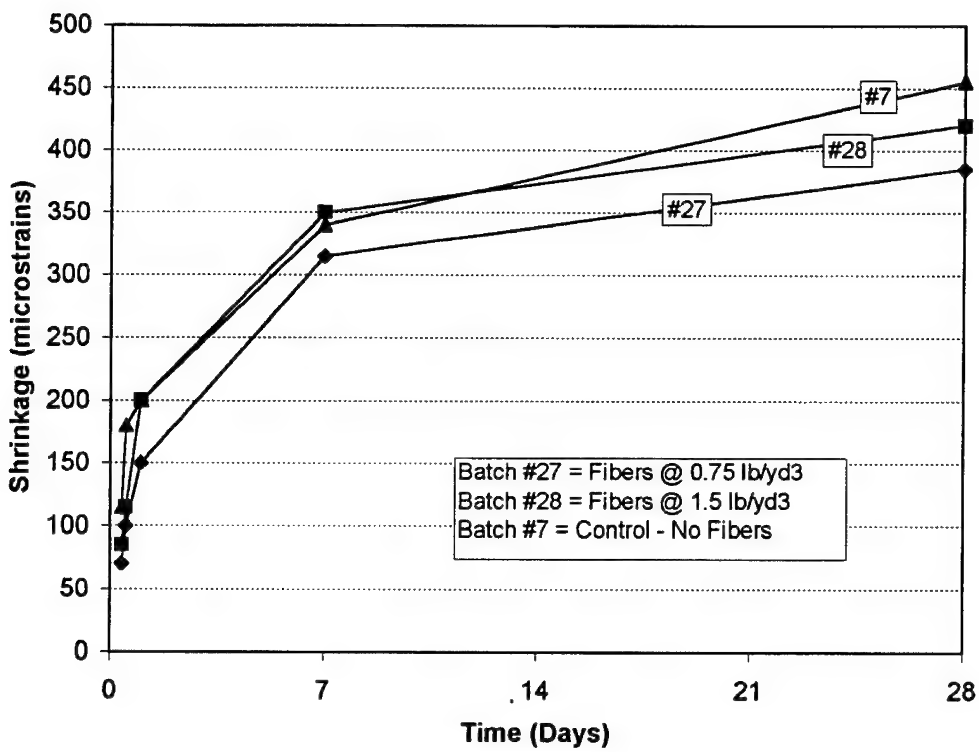

Figure 4.15 28 Day Shrinkage for Batches with Fibers

Figure 4.18 illustrates the 28-day shrinkage for batches with fibers. Batch #7 was added to the data as a control batch without fibers because no shrinkage prisms were cast for batch #26. Neither batch with fibers exceeded the shrinkage limit at 28 days of 500 microstrains.

The tensile strength of the batches with fibers was evaluated using the splitting cylinder method and the MOR method. Table 4.21 lists the tensile strength data for the batches with fibers.

Table 4.21 Tensile Strengths for Batches with Fibers

Cement Type			Type III	Type III	Type III
Cement Provider			Lonestar	Lonestar	Lonestar
Batch Number			**26**	**27**	**28**
Fibers	lb/yd^3		0	0.75	1.5
Tensile Strength (psi)	MOR	28 Day	730	865	860
	Splitting Cylinder	1 day	730	635	680
		28 day	790	690	840

The tensile strength data for these batches is a little confusing. The MOR data indicates that the batches #27 and #28, made with fibers, have a higher tensile capacity than batch #26 made without fibers. This data supports findings in the literature that fiber reinforcement increases the tensile capacity of concrete. However, splitting tensile data indicates that at 1day, the batch without fibers has a higher tensile strength than batches with fibers. At 28 days, the splitting tensile data indicates that the batch with fibers added at 0.75 lb/yd^3 has a lower tensile capacity than the batch without fibers. As a result, no firm conclusion can be drawn regarding the tensile strength of concrete with fiber reinforcement. However, the data does

indicate that fiber reinforcement at some dosages might increase the tensile capacity of the concrete at 28 days.

The final evaluation of batches with fibers centered on the bond performance of the patching material. Two testing methods were used to evaluate the bond strength of the patching material. The first was the slant shear method. Table 4.22 lists the slant shear test results for batches with fibers.

Table 4.22 Slant Shear Cylinder Data for Batches with Fibers

Cement Type			Type III	Type III	Type III
Cement Provider			Lonestar	Lonestar	Lonestar
Batch Number			**26**	**27**	**28**
Fibers	lb/yd^3		0	0.75	1.5
Slant Shear Bond	1 day	psi	5170	4905	5400
	28 days	psi	5240	5190	5230

All slant shear test results indicate substrate failures and not failures of the bond. Therefore, these values should not be considered actual bond strengths, but rather minimum strengths for the mixtures with fibers. This data does not indicate whether fibers act to increase the bond strength of the patching material.

The second method used for comparing the bond performance of batches with fibers to batches without fibers was the horizontal shear beam test. The beams were comprised of a flexurally reinforced plain concrete substrate with an overlay of patching material. For this test, 2 beams were made with fibers at dosages of 1.5 lb/yd^3 and 2 beams were made without fibers. Both sets of beams were reinforced to induce a horizontal shear failure prior to flexural failure. Table 4.23 lists the beam's

failure load along with the patching concrete compressive strength at the time of testing.

Table 4.23 Horizontal Shear Beam Data

Cement Type			Type III	Type III
Cement Provider			Lonestar	Lonestar
Batch Number			**29**	**30**
Fibers	lb/yd^3		0	1.5
Patching Material Compressive Strengt	psi		10685	10245
Beam Failure Load	kips	Beam #1	15.7*	21.02+
		Beam #2	21.24+	18.8+
Beam Failure Mode	Beam #1		flexural	Hor. Shear
	Beam #2		flexural	Hor. Shear

* - beam steel area = 0.4 in^2

+ - beam steel area = 1.15 in^2

It should be stressed that the purpose of this test was to ascertain whether fibers could improve the bond performance of the patching material, not to pinpoint the actual bond strength for the patching material. To this effect, the horizontal shear beam data is somewhat inconclusive. Two beams exhibited horizontal shear failures, and those two beams happened to be the beams with fibers. The first beam without fibers failed flexurally because it did not have enough reinforcement. Why the second beam without fibers failed in flexure is unclear. One possible explanation could be that the patching material without fibers actually develops slightly larger bond strength than the material with fibers. Pictures of each beam at failure are available in appendix A.

While some of the data collected about batches with fibers in this research is somewhat inconclusive, several observations can be made about the proposed patching material with fibers. First of all, it is possible maintain compressive strength and shrinkage requirements for the patching material with fibers. Second, MOR data indicates that the patching material with fibers develops a higher tensile capacity than the material without fibers. These observations combined with evidence from the literature that fibers can increase the life span of concrete repairs by enhancing cracking resistance, durability, and toughness, indicate that fibers could be added to the patching mixture, however they are not required.

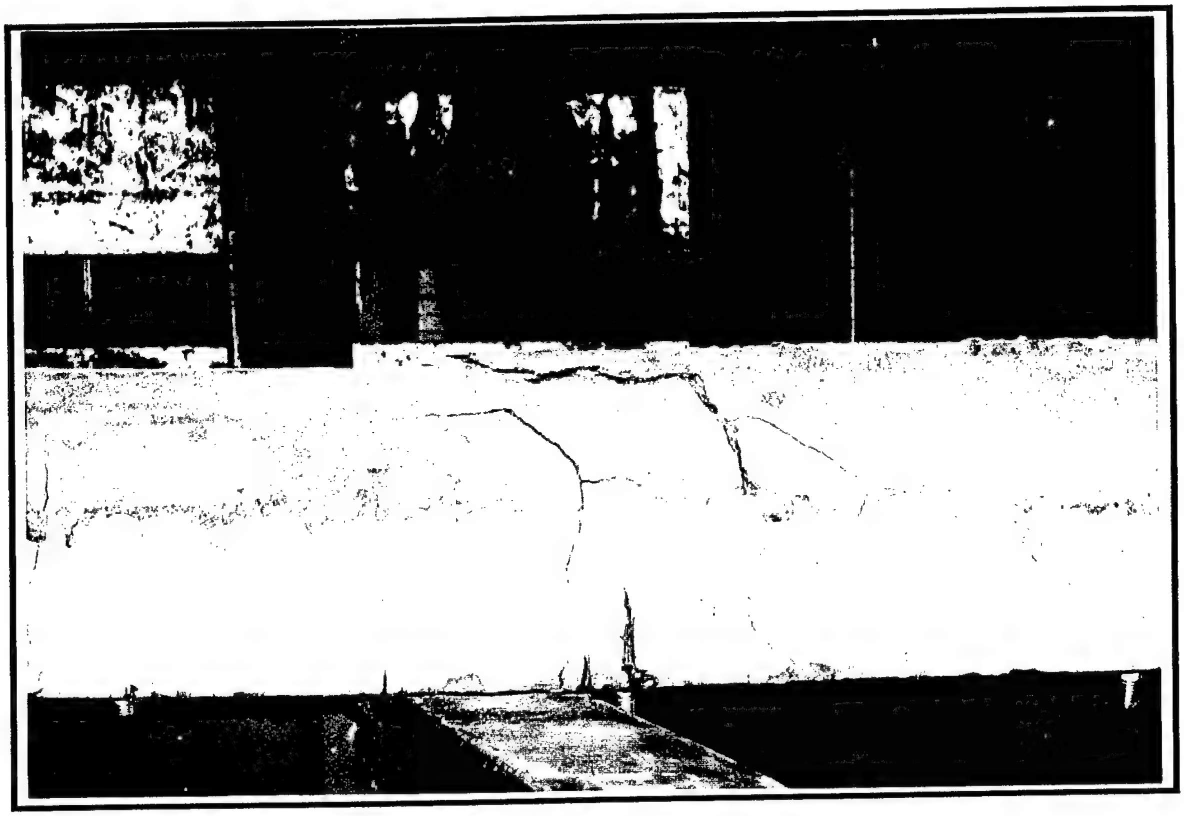

Figure 4.16 Beam Without Fibers #2 – Flexural Break

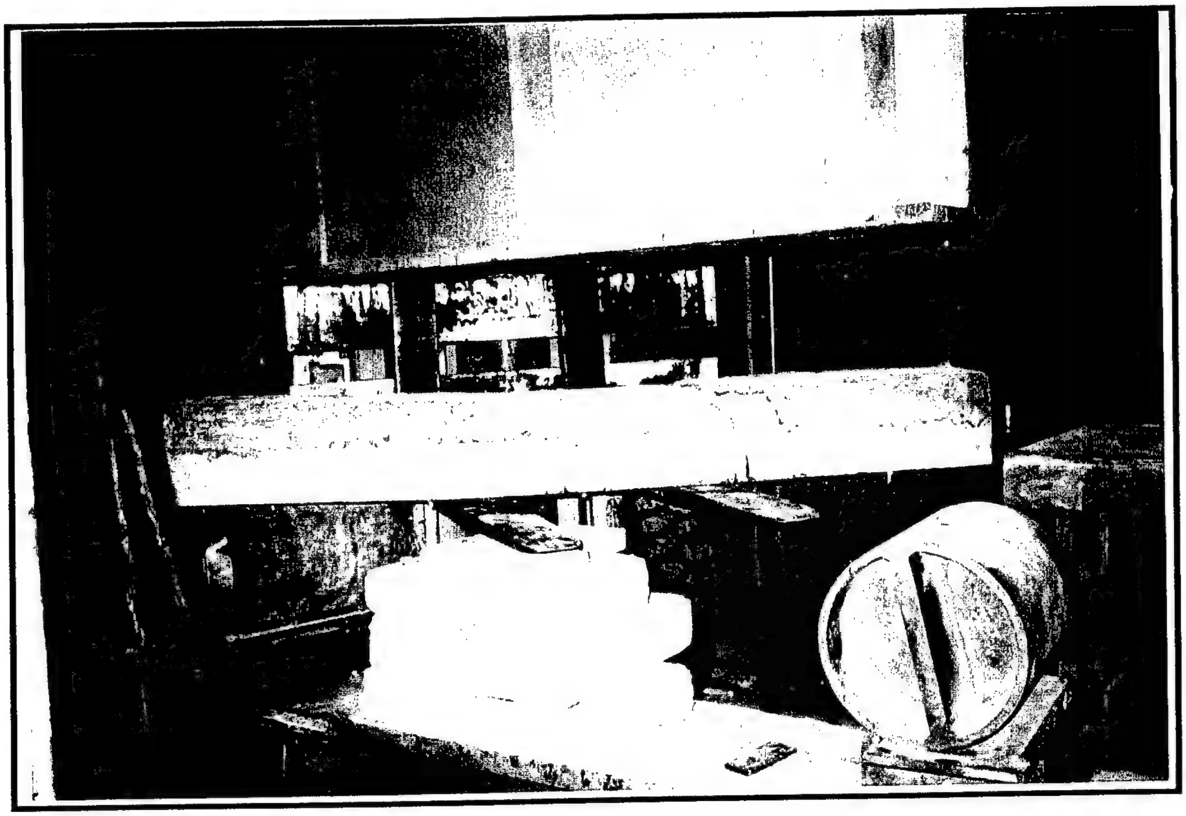

Figure 4.17 Beam Without Fibers #2 – Flexural Break

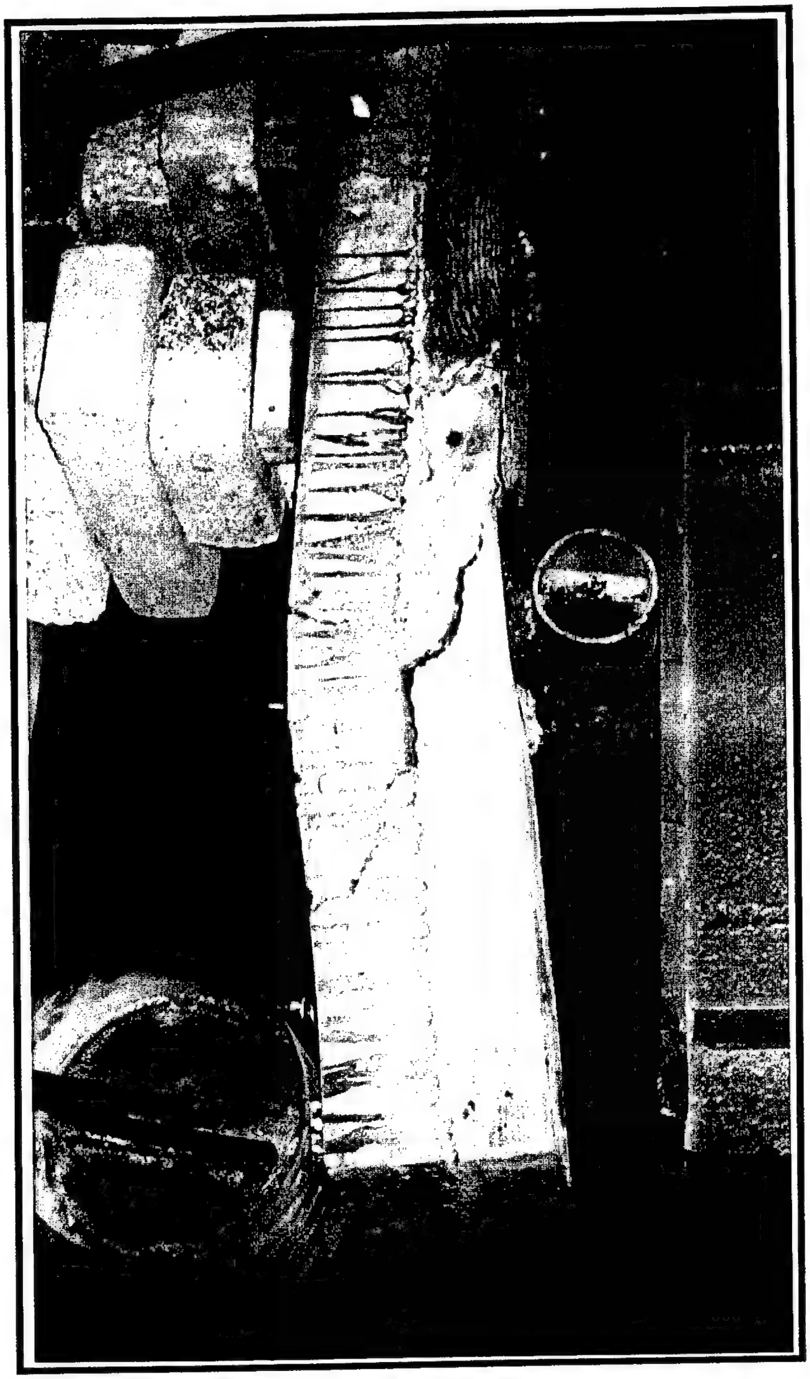

Figure 4.18 Beam With Fibers #1 – Horizontal Shear Failure

Figure 4.19 Beam With Fibers #1 – Horizontal Shear Failure

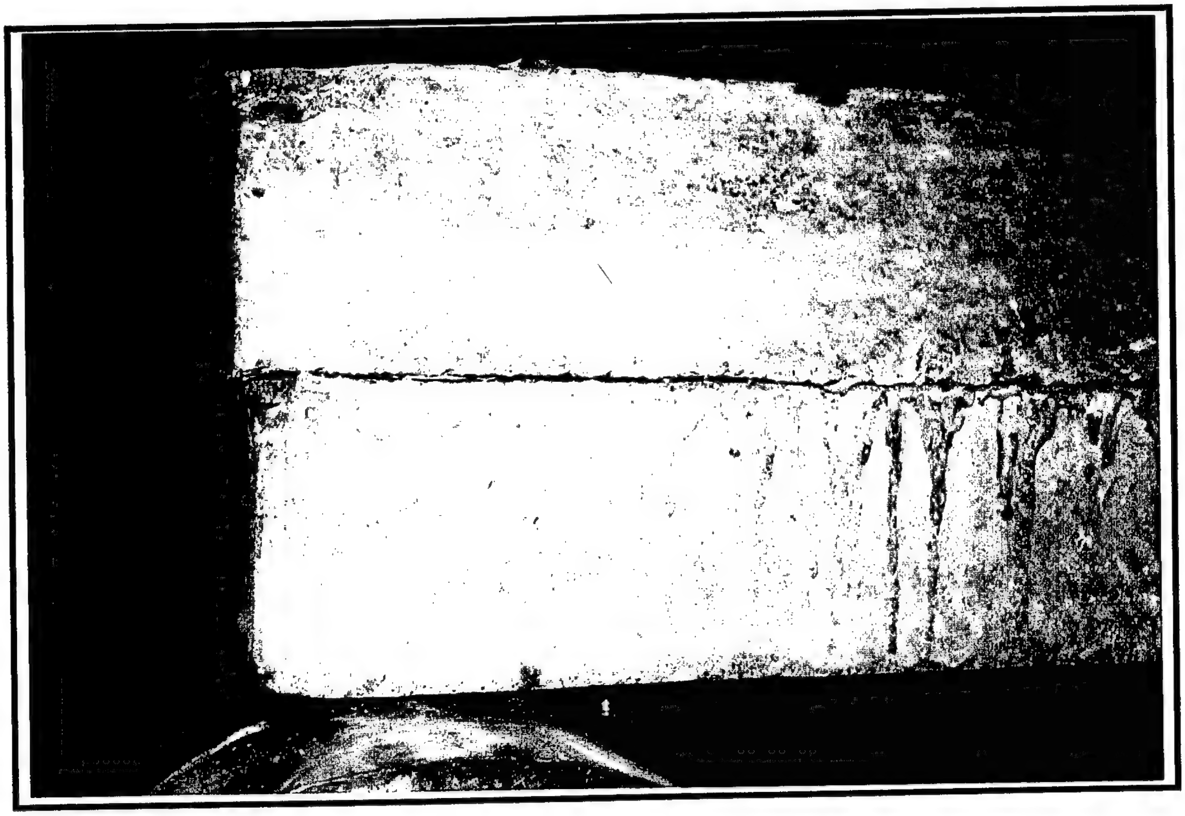

Figure 4.20 Beam With Fibers #2 – Horizontal Shear Failure

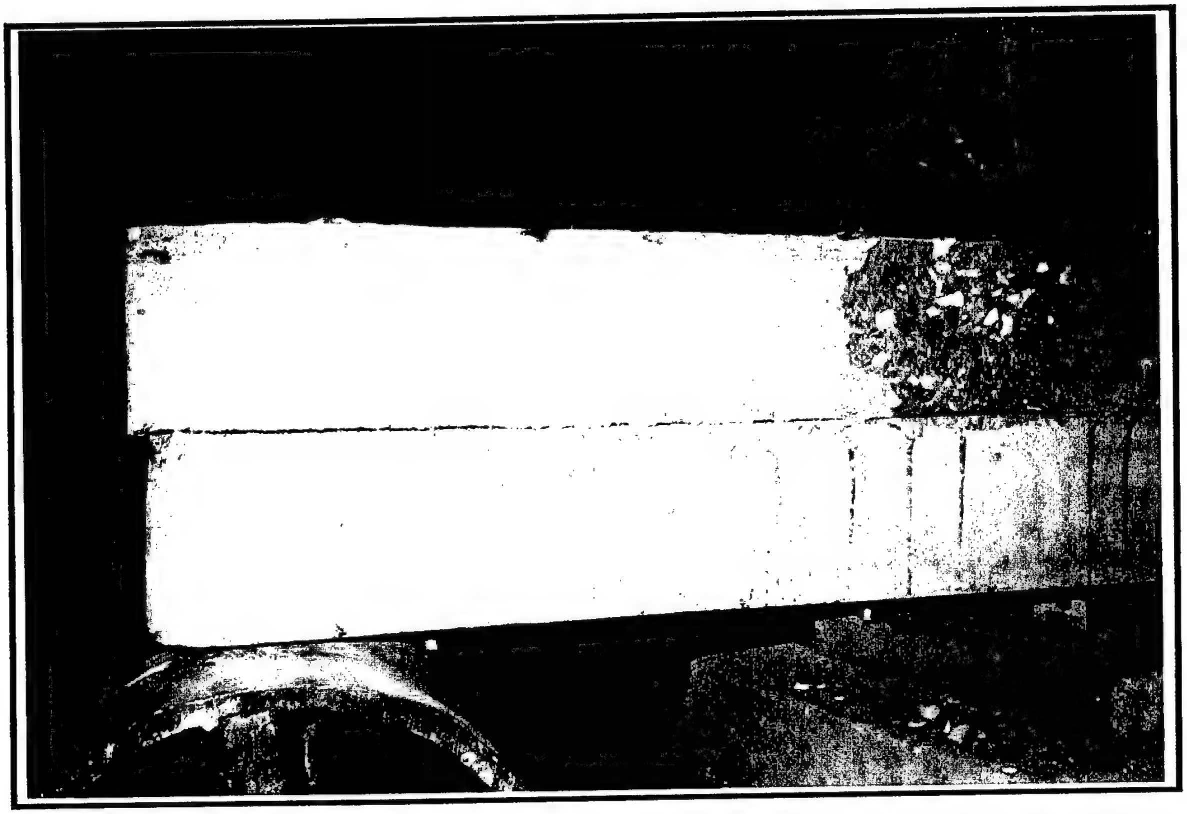

Figure 4.21 Beam With Fibers #2 – Horizontal Shear Failure

CHAPTER 5 FIELD EXPERIENCES WITH ODOT

5.1 TRIAL BATCHING

Field evaluation for the proposed patching material began in August of 1999. ODOT contacted personnel at Fears Engineering Laboratory and related they were having difficulties achieving adequate early compressive strengths with their portland cement concrete patching material. Their mixing proportions were based on proportions obtained from Fears Lab research personnel during the summer of 1998. These mixing proportions were developed for use with Holnam Type III cement which in 1999 was no longer commercially available. During trial batching, the contractor had used three different mixture proportions to try and come up with a material that would develop adequate compressive strength. Table 5.1 lists the three mixture proportions used by ODOT.

Table 5.1 ODOT Patching Material Mixture Proportions

Cement Type		Type III	Type III	Type III
Cement Provider		Lonestar	Lonestar	Lonestar
Batch Number		**ODOT# 1**	**ODOT #2**	**ODOT #3**
Cement Content	lb/yd^3	600	600	650
Coarse Aggregate	lb/yd^3	1770	1770	1770
Fine Aggregate	lb/yd^3	1410	1410	1410
w/c		0.35	0.35	0.28
HRWR (ADVA Cast)	gallons	0.70	0.70	0.70
Accelerator (DCI)	gallons	6.00	8.00	9.00

The table indicates that in order to increase compressive strengths from the first batch, ODOT increased the amount of accelerator. When that didn't work, they

increased cement content, removed water and increased the amount of accelerator for the third batch. Table 5.2 lists the 6 hour compressive strengths for the three batches.

Table 5.2 Compressive Strength of ODOT Patching Materials

Cement Type		Type III	Type III	Type III
Cement Provider		Lonestar	Lonestar	Lonestar
Batch Number		**ODOT# 1**	**ODOT #2**	**ODOT #3**
Compressive Strenght (psi)	6 hours	2740	1640	2780

Although two of these batches achieve a compressive strength greater than the required 2500 psi at six hours, they were also batched during the heat of a summer day. Since the patching for this field project was going to occur at night, the contractor was concerned that the material would not develop enough strength during the cooler hours of the evening.

Personnel at Fears lab assisted ODOT and the patching contractor Gilbert-Central, in trial batching to find a solution to their problems. Prior to trial batching, ODOT and Gilbert Texas were provided with the proposed patching mixture proportions developed during this research project. These mixture proportions are provided in table 5.3.

Table 5.3 Proposed Patching Material Mixture Proportions

Cement Content	lb/yd^3	700
Coarse Aggregate	lb/yd^3	1787
Fine Aggregate	lb/yd^3	1337
w/c		0.3
HRWR (ADVA Cast)	oz/cwt	13
Accelerator (DCI)	oz/cwt	110

When the first trial batches were mixed, the resulting material was extremely watery and the aggregate was segregating from the cement paste. At this point it became evident that something was wrong with the batching procedure. Low unit weight and high air content measurements indicated an error in the batching proportions. After checking the calibration on the portable auger mixer being used to batch the concrete, it was determined that the accelerator was being added to the mix at twice the specified dosage. At this point, it was emphasized to the contractor and to the ODOT personnel present the importance of quality control in the form of measuring such properties as unit weight and slump during patching projects. Such quality control measurements would ensure quick and efficient diagnoses and correction of any batching problems encountered in the field. Once the calibration problem was corrected, patching material was produced that performed similarly with the material produced in the lab.

Table 5.4 Compressive Strength of Trial Batches (Concrete Provided by Gilbert Texas)

Time	Trial Batch #1	Trial Batch #2
4.5 hours	3350 psi	2750 psi
5 hours	3690 psi	3260 psi

Once the patch material was determined to be adequate, it was implemented into field repairs.

5.2 FIELD EVALUATIONS

Once in the field, both the contractor and the ODOT personnel deemed the patching material a success. The few problems that were encountered involved using the material during cooler ambient conditions and not properly insulating or failing to

achieve a high enough initial concrete temperature. Field patches were evaluated based solely on their compressive strength. Once compressive strength had exceeded 2500 psi, the patch was considered ready for traffic.

Table 5.5 contains field data obtained from ODOT personnel from the I-40 Cross-town Patching Project. All compressive strengths reported in this table represent data collected from only one cylinder break.

Table 5.5 I-40 Cross-town Patching Project Data

Date	Air Temp °F	Concrete Temp. (°F)	Age at Test (hours)	Compressive Strength (psi)
8-19-99	75	N/A	5	2550
8-26-99	73	N/A	3.5	2650
9-12-99	N/A	89	5	2680
9-15-99	65	105	3.5	3100
9-16-99	63	102	6.25	4160
9-17-99	65	108	3.5	3640
9-21-99	61	100	4.25	2520
9-22-99	58	110	4.5	2560
9-23-99	66	125	3.5	3220
9-24-99	61	113	3.75	2880
9-30-99	49	105	6.25	4430
10-1-99	50	115	4.25	2770

N/A – not available

This data illustrates the versatility of the patching material when used in the field under varying ambient conditions. While the effects of initial concrete temperatures over 100°F on the patching material were not evaluated in the laboratory, they seem to produce higher compressive strengths at much earlier ages. It should be noted that the patching contractor benefits monetarily if the patches reach an acceptable compressive strength as quickly as possible. In any case, until there is evidence that high initial concrete temperatures can be detrimental to the performance

of the patching material, the practice of using the material at high temperatures should not be discouraged.

Fears Lab personnel made visual inspections of the patches 1-week and 6 months after placement. These inspections found the patches in good working order with few exceptions. Figure 5.1 illustrates patches that have been prepared by saw cutting around the damaged pavement and then chipping around the reinforcing bar. Figure 5.2 illustrates personnel employed by Gilbert Central Construction Contractor placing and finishing a patch. Figure 5.3 illustrates a patch one day after placement. No cracks are apparent in the patch. Figure 5.4 illustrates a patch 6 months after placement. Figure 5.5 illustrates a failed patch. Judging from wear, this patch appeared to have been installed prior to the development of the patching material described in this research project. The patch age and the patching material utilized are unknown.

The patch is in good condition with no apparent cracking. Figure 5.6 illustrates a pavement failure. This failure is along pavement joint which is typical of many pavement failures found on this roadway.

5.3 CONCLUSION

The conclusion that can be drawn from this field experience is that the proposed patching material can be consistently produced in the field and can yield patches that perform well up to six months after placement without any evidence of eminent failure.

Figure 5.1 Preparation for Patch – I-40 Crosstown Bridge Patching Project, August 1999

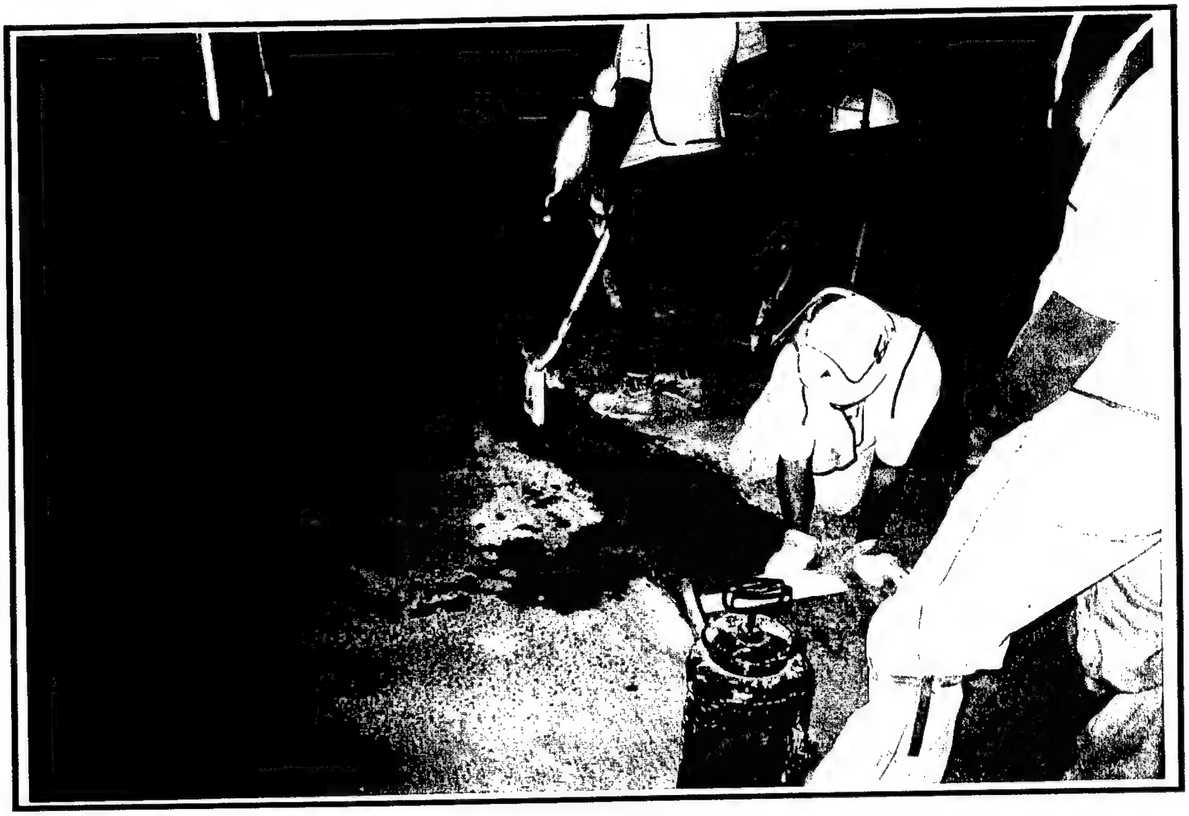

Figure 5.2 Placing The Patch – I-40 Crosstown Bridge Patching Project, August 1999

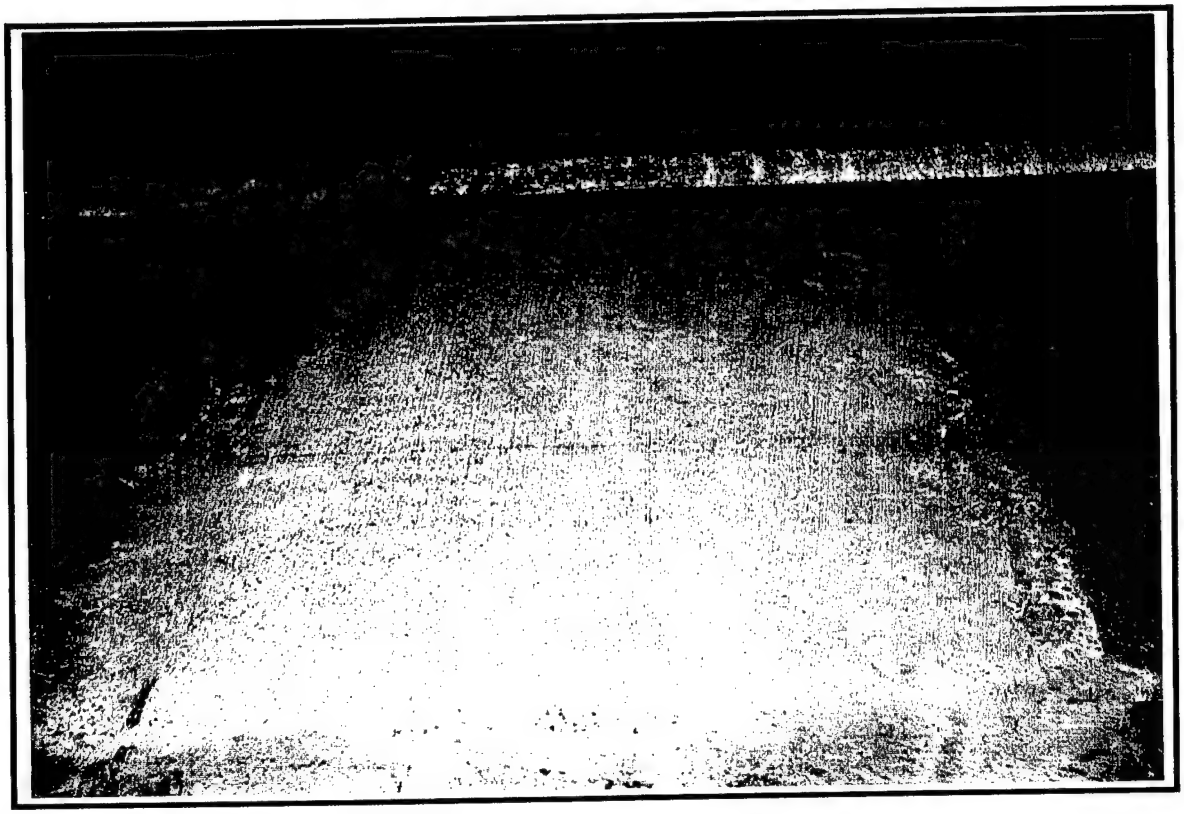

Figure 5.3 Finished Patch, 1 Day – I-40 Crosstown Bridge Patching Project, August 1999

Figure 5.4 Completed Patch, 6 months, I-40 Crosstown Bridge Project, May 2000

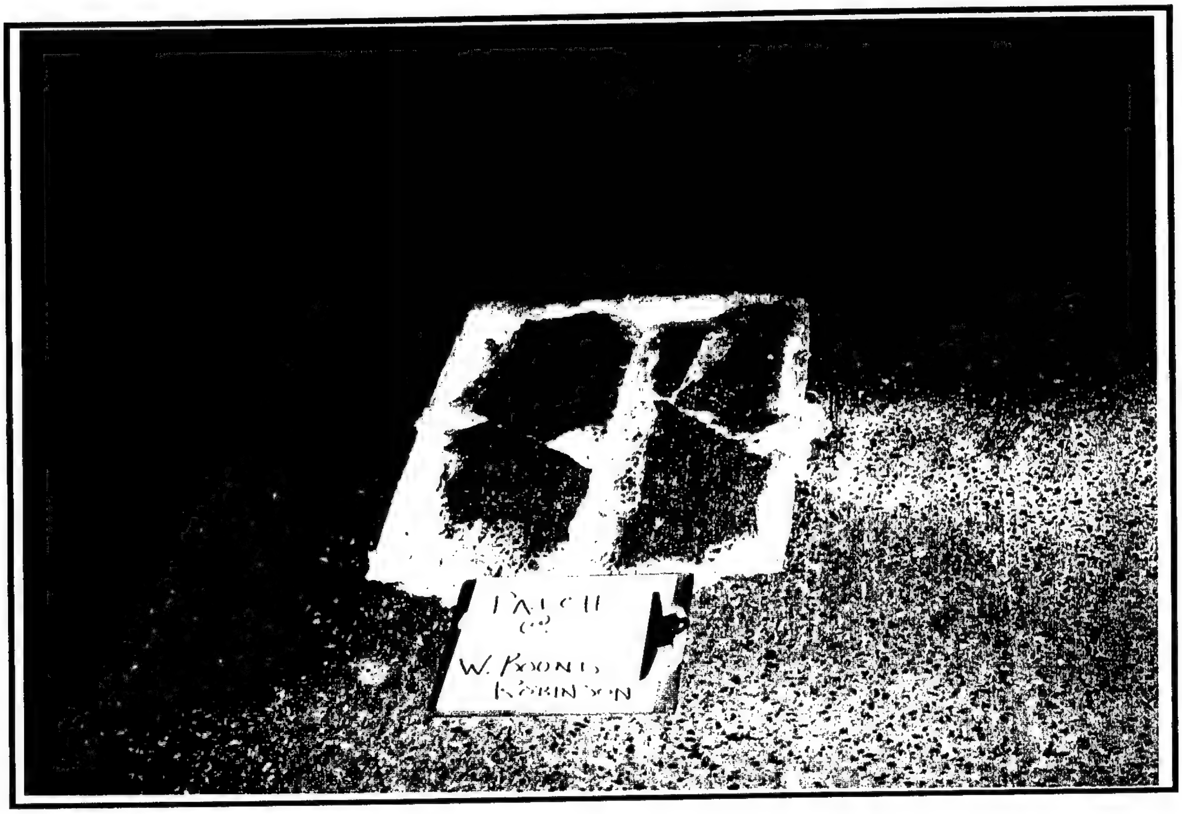

Figure 5.5 Failed Patch, Age Unknown, I-40 Crosstown Bridge Project, May 2000

Figure 5.6 Pavement Failure, I-40 Crosstown Bridge, May 2000

CHAPTER 6 RECOMMENDED GUIDELINES FOR FIELD INSTALLATION

6.1 THE MATERIAL

The following table lists the PCC mixture proportions determined to produce the optimum performance for a patching material using the cements, aggregates and admixtures employed in this investigation. The materials described in this section were materials used during the laboratory investigation for this project. It is not a recommended requirement that these specific materials be utilized during field applications. However, substitutions for the materials described must be tested by trial batching to assure that the material performance is adequate. The mixture proportions were identical for both type I and type III cements.

Table 6.1 Mixture Proportions for Proposed Patching Material

Cement Content	lb/yd^3	700
Coarse Aggregate	lb/yd^3	1787
Fine Aggregate	lb/yd^3	1337
w/c		0.30
HRWR (ADVA Cast)	oz/cwt	13
Accelerator (DCI)	oz/cwt	110

6.1.1 Cements

This project explored the use of both type I and type III cements. The type I cement used in the investigation was manufactured by Holnam in Midlothian, Texas and the type III cement was manufactured by Lonestar in Pryor, Oklahoma. The w/c ratio is determined by dividing the weight of water in the concrete mix by the weight

of cement. It should be noted that cements purchased from different sources are likely to perform differently in a specific mix design. Consequently, if different cements are to be used than the ones utilized during the research, then trial batching prior to field placement is necessary to ensure adequate performance of the patch material.

6.1.2 Aggregates

The fine aggregate used in the patch mix design is named "Dover Sand" after the town nearby where the sand is mined. The sand is natural river sand and is washed to conform with ASTM C 33. Its relevant material properties are included in Table 6.2. The Coarse Aggregate used in the patch mix designs is #67 crushed limestone.

Table 6.2 Properties of Fine Aggregates

Fine Aggregate Properties	
Fineness Modulus (FM)	2.5
Specific Gravity	2.63
Saturated Surface Dry (SSD) Moisture Content	0.70

Table 6.3 Properties of Coarse Aggregates

Coarse Aggregate Properties	
Dry Rodded Unit Weight	101.0
Specific Gravity	2.67
Absorbtion Content (AC)	0.86

These aggregate materials were provided by Dolese Brothers Concrete in Oklahoma City and are readily available throughout the state of Oklahoma.

6.1.3 Admixtures

The HRWR used in the patching mixture proportions was **ADVA Cast©** manufactured by Grace Construction Products®. The optimum dosage rate for this HRWR was determined to be 90 oz/yd^3 or 13 ounces per hundred weight (oz/cwt) of cement. This HRWR was selected because of its unique ability to add workability without retarding the hydration of the cement in the concrete.

A concrete accelerator, DCI, was also added to the patch mix to increase the rate of hydration. DCI© is manufactured by Grace® Construction Products and is marketed as a corrosion inhibitor, however it is also effective as a concrete set. Due to the high dosage rate of the liquid accelerator, ½ of the weight of the accelerator is counted as water when figuring the w/c ratio for the patching mixture proportions.

6.1.4 Fibers

While fibers have not yet been evaluated in the field, the research data and data obtained from the literature suggest that there could be some benefit to adding polypropylene fibers to the patching mix. If fibers are added they should be dosed at around 1.5 pounds per cubic yard of concrete. Trial batching should be used to insure that the addition of fibers will not adversely effect the mix.

6.2 MIXING EQUIPMENT

Two mixing methods have bee utilized during field implementation. The first has utilized a rotary drum mixer and the second an auger mixer. Any method for mixing the patching material should

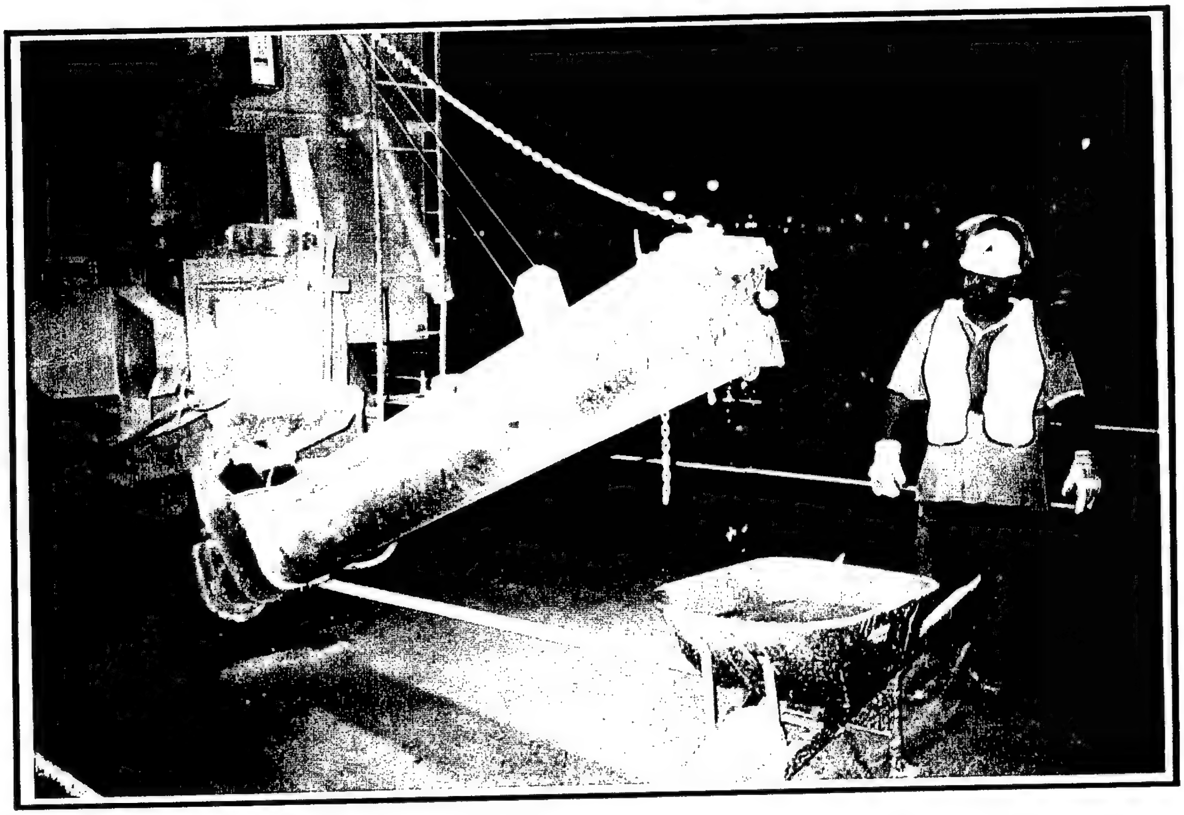

Figure 6.1 Auger Mixer, I-40 Crosstown Bridge Project, August 1999

share two important characteristics: 1) It should allow the patching material to be mixed in the field. 2) It should allow for the rapid placement of the patching material. The rapid strength gain criteria for the patching material resulted in a concrete mix that achieves an accelerated rate of hydration. Consequently, the material should be mixed on site and then promptly placed in the patch in order to prevent the material from "sticking" to the mixing equipment. Because of this concern, it is not recommended that the patching material be supplied by a ready mix plant via mixing truck.

6.3 TRIAL BATCHING

All batching in the field must be preceded by trial batching using the same mixing methods and materials that are to be used in the field. Changes to proportions or materials may be made during trial batching to optimize the performance of the patching material for a specific project. The material should meet the following testing parameters during trial batching to verify that it will perform adequately in the field.

The achievement of a specific unit weight value is not critical during trial batching. However, consistent unit weight values should be attained during trial batching so that the unit weight of the material in the field can be compared with the trial batch unit weight. Compressive strength tests should make use of two cylinder breaks per test to assure confidence in the test result. Either 4" x 8" or 6" x 12" cylinders may be used for testing. However, 4"x 8" cylinders would decrease the amount of material required for testing and would simplify the transportation of the

cylinders from the patch site to the testing station. Similarly, shrinkage tests should be conducted on at least two and preferably three test specimens to insure accuracy.

Table 6.4 Trial Batching Testing Parameters

Compressive Strength ASTM C 39	≥ 2500 psi @ 6 hours
Shrinkage ASTM C 490	≤ 500 microstrains @ 28 days
Slump (initial) ASTM C 143	2" – 6"
Slump Life ASTM C 143	≥ 1" @ 30 minutes
Fresh Concrete Temp. ASTM C 1064	≥ 75 deg. F.
Unit Weight ASTM C138	≈ 149 – 150 lb/ft^3

At the conclusion of trial batching, all trial batching mixture proportions along with all test results should be submitted to the project's governing authority for determination of acceptability.

6.4 PATCHING IN THE FIELD

6.4.1 Preparing the Patch

The patch needs to be prepared properly prior to the placement of the patching material in order to insure optimum performance of the patch. This preparation should include saw cutting around the damaged pavement area. The damaged pavement should then be lifted out, in the case of full depth patches or chipped out in the case of partial depth patches. Care should be taken not to damage the substrate or surrounding concrete during this procedure. Any damage of the substrate or of the surrounding pavement could result in a premature patch failure. Once the damaged

pavement area is removed, the substrate should be prepared by blasting with either abrasive, shot, or water. It has been established in literature that these methods do not result in extensive bruising or damage to the substrate (Warner et. al. 1998). After sandblasting, the substrate should be cleaned of any loose material. Once the substrate is clean it should then be moistened until the surface has a wet appearance without any standing water. This prevents patch material moisture from being absorbed by a dry substrate thereby removing necessary water from the patching concrete. At this point, the patch is ready for the placement of the patching material.

6.4.2 Mixing of Patch Material

Once the area to be patched has been prepared, mixing of the patch material may begin. If a drum mixer is being utilized to mix the patching material, then the following sequence should be followed for charging the mixer:

1. Coarse Aggregate (Rock)
2. Half of the water
3. Fine Aggregate (Sand)
4. Cement
5. Accelerator
6. High Range Water Reducer (HRWR)

Once all materials have been added, mixing should continue until all materials are thoroughly and evenly distributed. Prior to the addition of the HRWR, the material will seem very dry and rocky. It may take 2-3 minutes for the HRWR to begin to lubricate the mix, however once it begins to act, the change will be apparent. In the

case of the auger mixer, all materials are added at the base of the auger and mixing occurs as the material proceeds up the auger stem.

6.4.3 Placing of Patch Material

Once the material is mixed, it should be placed in the patch as quickly as possible. The material will remain relatively workable for 20-30 minutes depending on its initial concrete temperature. However, agitation will extend the life of the material if longer working times are desired. During placement, the material should be mechanically vibrated to insure complete consolidation of the material within the patch. Once the material has been placed, the surface should be worked with trowels to match the elevation of the existing pavement and excess material should be removed. Insulating blankets should then cover the patch until the patch is opened for traffic to aid in the hydration process of the concrete. After the patch has cured for approximately 1 hour, broom finishing or other procedures may be used to texture the surface of the patch.

6.4.4 Evaluating Patch Material in the Field

To insure the consistency and the quality of the patching material, evaluation of the material should be made each time it is used in the field. It is suggested that the patch material be tested for compliance with the following parameters.

Table 6.5 Patch Field Quality Control Parameters

Fresh Concrete Temp. (ASTM C 1064)	$> 75°$ F
Compressive Strength (ASTM C 39)	$\geq$ 2500 psi @ 6 hours
Unit Weight (ASTM C 138)	determined during trial batching

All tests should be performed in accordance with ASTM specifications. Additionally, compressive strength specimens should be cured in the same manner as the patches (i.e. in the field under an insulating blanket.) It should be noted that the patching material is highly sensitive to variations in moisture. This sensitivity is evident in the relatively broad range of acceptable slumps. If the material appears more watery than normal, this does not necessarily mean that the material is unacceptable. A more reliable indicator of material acceptability will be the unit weight. If the unit weight appears to be significantly less than normal on a watery mix, then chances are that the material is unacceptable. If not, compressive strength tests should indicate whether the material is acceptable or not. Compressive strength tests should include at least two cylinder breaks and preferably three to insure the quality of the results.

6.4.5 Weather Conditions

It is not recommended that this material be used when the ambient temperature falls below 50° F. Below this temperature, the patching material may not achieve adequate compressive strength in the required time. Use of this material between temperatures of 50° F and 70° F may require that the water and aggregates be heated to insure the concrete reaches its required compressive strength. Adequate insulation of the concrete at this temperature range is also a must to insure that the material reaches its prescribed strength in the time allotted. The placing of this material during periods of precipitation is obviously not recommended.

CHAPTER 7 SUMMARY AND CONCLUSIONS

To summarize, this thesis has presented research with the objective of developing portland cement patching products and procedures for the State of Oklahoma. The steps taken toward this objective have included a review of past research, a laboratory testing program for the development and evaluation of a portland cement concrete patching material, and a field implementation where the material developed in the lab was evaluated for realistic application. The results of this effort have lead to the development of the following conclusions:

- Cement source is an important factor in developing High Early Strength (HES) concrete for patches. Differing fineness values of cements from various sources played a more significant role in the development of early strength than did cement chemistry.
- Satisfactory patching materials can be produced using non-proprietary portland cement concrete products.
- The addition of Shrinkage Reducing Admixtures (SRA) to portland cement concrete (PCC) patching material mixture proportions reduced shrinkage at early ages and at 28 days.
- Over time, the differences in shrinkage values between concrete with SRA added and concrete without SRA decreased.
- Concrete with SRA produced lower compressive strength values at early age than concrete without SRA added.

- Adding various admixtures to the concrete at the same or similar proportions will not always result in a material with similar performance characteristics.
- As the amount of DCI decreased in the PCC patching material, the early compressive strengths decreased.
- The addition of polypropylene fibers to the pcc patching produced inconclusive tensile strength results. Whereas MOR values increased with the addition of fibers, splitting tensile values displayed no discernable trend between concrete made with and without fibers.
- The bond strength was sufficient to produce substrate compressive failures for slant shear specimens using the PCC patching material with and without fibers.

The following recommendations are made for further research in this area:

- The effect blending HAC and portland cement has on other properties such as shrinkage, RCIP, freeze/thaw durability etc.
- The development of dosage levels for alternate brands of admixture.
- The effect of fiber reinforcement on the bond strength of the patching material.
- The effect of fiber reinforcement on the freeze/thaw durability of the patching material.

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APPENDIX A – MANUFACTURER PRODUCT DATA

ADVA Cast

Superplasticizer ASTM C 494, Type F

DESCRIPTION

ADVA Cast Superplasticizer is a high range water-reducing admixture. It is a low viscosity liquid which has been formulated by the manufacturer for use as received. ADVA Cast Superplasticizer contains no added chloride. ADVA Cast Superplasticizer is formulated to comply with specifications for Chemical Admixtures for Concrete, ASTM C 494 as a Type F admixture. The weight for 3.785 liters (1gal) is approximately 4.08 kg (9lbs).

DISPERSION

ADVA Cast Superplasticizer is a superior dispersing admixture having a marked capacity to disperse the cement agglomerates normally found in a cement-water suspension. The capability of ADVA Cast Superplasticizer, in this respect, exceeds that of normal water-reducing admixtures.

USES

ADVA Cast Superplasticizer produces concrete with extremely workable characteristics referred to as high slump, flowing concrete. It also allows concrete to be produced with very low water/cement ratios for high strength. ADVA Cast Superplasticizer is ideal for use in precast and precast/prestress applications where it is desired to keep the water/cement ratio to a minimum and still achieve the degree of workability necessary to provide easy placement and consolidation.

ADDITION RATES

Addition rates of ADVA Cast Superplasticizer can vary with type of application, but will normally range from 195 to 780 mL/100 kg (3 to 12 fl oz/100 lbs) of cement. For best results, ADVA Cast Superplasticizer should be added to the initial mix water. At a given water/cement ratio, the slump required for casting can be controlled by varying the addition rate. Should conditions required using more than recommended addition rates, please consult your Grace Representative.

COMPATIBILITY

In conrete containing ADVA Cast Superplasticizer the use of an air-entraining agent is recommended to provide suitable air void parameters for resistance against freeze/thaw attack. Due to synergistic effects between ADVA Cast Superplasticizer and air-entraining agents, the quantity of air-entraining admixture added to ADVA Cast Superplasticizer admixtured concrete may be reduced, please consult your Grace Representative.

Most Type A water reducers or Type D water-reducing retarders are compatible with ADVA Cast Superplasticizer as long as they are separately added to the concrete. Pre-testing of the concrete should be performed to optimize dosages and

addition time of these admixtures. The admixtures should not contact each other before they enter the concrete.

PACKAGING
ADVA Cast Superplasticizer is available in bulk, delivered by metered tank trunks, in 1250 L (330 gal) disposable totes, and in 210 L (55 gal) drums. ADVA Cast Superplasticizer contains no flammable ingredients.

It will begin to freeze at approximately 0 deg C (32 deg F), but will return to full strength after thawing and thorough agitation.

In storage, and for proper dispensing, ADVA Cast Superplasticizer should be maintained at temperatures above 0 deg C (32 deg F).

Sikament 10 ESL

Extended Slump Life High Range Water Reducer (Types A and F)

DESCRIPTION

Sikament 10 ESL is a high range water reducer and superplasticizer formulated to provide extended slump life.

Sikament 10 ESL is a unique fomaldehyde-free product based on a vinyl copolymer. It is non air-entraining admixture that does not interfere with the air-void system in the concrete matrix.

Sikament 10 ESL does not contain formaldehyde, calcium chloride or any other intentionally added chlorides and will not initiate or promote the corrosion of steel present in the concrete.

APPLICATIONS

Sikament 10 ESL may be used as a plant added, ready mix or precas, high range water reducer to obtain desired plasticity and maintain slump for up to two hours. Controlled set times make Sikament 10 ESL ideal for horizontal and vertical slipform applications.

ADDITION RATES

Dosage rates will vary according to materials used, ambient conditions and the requirements of a specific project. Sika recommends dosage at 6-20 fl. oz per 100 lbs. of cement for general concrete applications.

Dosages outside the recommended range may be used where specialized materials such as micro-silica are specified, extreme ambient conditions are encountered or unusual project conditions require special consideration. Please contact your Sika representative for more information and assistance.

MIXING

For best superplasticizing results, add Sikament 10 ESL directly to freshly mixed concrete in the concrete mixer at the end of the batching cycle.

Sikament 10 ESL may also be dispensed as an integral material during the regular admixture batching cycle, or into freshly mixed concrete in a Ready-Mix truck at the concrete plant or at the jobsite.

To optimize the superplasticizing effect, after the addition Sikament 10 ESL Sika recommends that the combined material be mixed for 80-100 revolutions or approximately 6 minutes, either in the concrete mixer or in the Ready-Mix truck.

PACKAGING

Sikament 10 ESL is available in 55 gallon drums and bulk delivery.

STORAGE AND SHELF-LIFE

Sikament 10 ESL should be stored at above 35 deg F. If frozen thaw and agitate thoroughly to return to normal state.

DCI Corrosion Inhibitor

Corrosion Inhibitor ASTM C 494 Type C

DESCRIPTION

DCI corrosion inhibitor is a liquid added to concrete during the batching process. It chemically inhibits the corrosive action of chlorides on reinforcing steel and prestressed strands in concrete. It also promotes strength development of the concrete while meeting ASTM C 494 requirements as a Type C admixture. One gal of DCI weighs 10.7 lbs. DCI contains a minimum of 30% calcium nitrite.

USES

DCI is recommended for all steel-reinforced, post tensioned and prestressed concrete that will come in contact with chlorides from deicing salts or a marine environment. Examples are parking garage decks and support structures, bridge decks and prestressed member, and structures in marine environments. It may also be used in concrete where chlorides are added during manufacture.

ADDITION RATES

Recommended addition rates range from 2.0 to 6.0 gal/yd^3. The level of corrosion protection increases in proportion to the dosage. The project specification will indicate the addition rate. In the absence of a specified dosage, or where needed to offset premixed chlorides, call your Grace admixture technical representative.

DCI also increase the early strength of a concrete mixture and may have an accelerating action on setting time. These effects become more pronounced as the addition rate rises. Control of setting time can be achieved with retarding admixtures.

CEMENT COMPATIBILITY

DCI corrosion inhibitor is compatible with all types of portland cement, and concretes containing pozzolans. However, due to the significant variation between cements, even the same type may result in differences in cement response to DCI. This is especially true with respect to the effect on setting time, which also influences slump retention.

MIX WATER REDUCTION

Mix water adjustment is essential to account for the water in DCI and thus maintain the desired water/cement ratio. The mix water added a the batch plant must therefore be reduced to compensate for the addition of the corrosion inhibitor. The adjustment factor is 7.0 lbs. of water per gal of DCI.

COMPATIBILITY WITH OTHER ADMIXTURES

DCI corrosion inhibitor can be used in conjunction with other admixtures – including air entraining admixtures, water reducers, superplasticizers, set-retarders, and microsilica – without impeding their performance.

SET ACCELERATION

At all recommended addition rates, DCI corrosion inhibitor may accelerate concrete setting times, which may also aggravate slump loss. To extend the set time to a more normal duration, separately add a retarder.

AIR ENTRAINMENT

DCI corrosion inhibitor at the normal addition rates may moderately reduce the entrained air content. It may be necessary to increase the dosage of the air-entraining admixture to compensate.

PACKAGING AND AVAILABILITY

DCI corrosion inhibitor is available in bulk quantities by Grace Construction Products metered systems, or, in 55 gal drums.

Sika Rapid-1

Non-chloride, hardening accelerator

DESCRIPTION
Sika Rapid-1 is a non-chloride hardening accelerator. Sika Rapid-1 contains no calcium chloride or any other intentionally added chlorides and will not intiate or promote the corrosion of reinforcing steel present in the concrete.

Sika Rapid-1 meets the requirements of ASTM C-494 Type C accelerating admixtures, and AASHTO M-194 Type C.

APPLICATIONS

High Early Strength Concrete:
Sika Rapid-1 delivers excellent results in normal and hot weather conditions where very high early strengths are required.

Conventional accelerators promote early stiffening of the concrete, making it unworkable within a short period of time. Sika Rapid-1 is designed for applications where early stiffening (slump loss) is not desirable but high early strengths must be obtained within a specified time.

DOSAGE
To promote high early strength, Sika Rapid-1 may be used at the reate of 8-48 fl. oz. Per 100 lb. cement.

When used to protect concrete from freezing, dosage will vary with different brands of cement and ambient temperatures and higher dosages may be necessary. Sika recommends that trial mixes be performed to determine the most efficient dosage.

USE WITH OTHER ADMIXTURES
Sika Rapid-1 performs well in combination with other admixtures such as non-retarding water reducers, high range water reducers and air entraining agents.

Do not mix Sika Rapid-1 with expansion agents or shrinkage compensating agents.

MIXING
Add correct amount of Sika Rapid-1 at the concrete plant or into ready mix truck at the job site. The admixture may be added manually or by automated dispenser directly into the sand or into the water line at the batch plant.

When used in combination with other admixtures care must be taken to dispense each admixture separately into the mix. Do not mix with dry cement.

PACKAGING
55 gallon drums and bulk delivery.

STORAGE AND SHELF LIFE

Sika Rapid-1 will begin to freeze at 25 def F. If frozen, thaw slowly and agitate thoroughly to return to its normal state before use.

BURKE FAST PATCH 928®

High-Alumina Cement Based Concrete Repair Material

APPLICATION INSTRUCTIONS

Surface Preparation: Remove all loose, unsound or contaminated concrete from area to be repaired. Square off and either vertical cut or under cut the repair area edges. Remove concrete to the depth as required by the traffic type from the following table:

PATCH THICKNESS LIMITATIONS

APPLICATION	UNEXTEDED MIX		EXTENDED MIX	
LOAD, TRAFFIC	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM
Light. cars	0.5 in. (13mm)	2 in.(50mm)	1 in. (25mm)	Full Depth
Heavy. trucks	not recommended		2 in. (50mm)	Full Depth

Note: All applications over 2 in. (50mm) in thickness must be extended by pea gravel addition (see mixing).

When schedule permits. repair area should be kept continuously damp for one hour. Then immediately before patch placement, all standing water must be removed and the surface water must be allowed to evaporate (sheen should disappear but surface should appear darkened by moisture). When rapid turnaround is desired, do not wet repair area, unless time for surface drying can be allowed.

MIXING RATIOS, EXTENSION YIELD DATA

FAST PATCH 928	EXTENSION	MIXING WATER	3/8 PEA GRAVEL	ESTIMATED YIELD
50 lb. (22.7kg)	None	3.25 U.S. qt. (3.1L)	None	0.416 ft^3 (0.012m^3)
50 lb. (22.7kg)	Min.(50%)	3.25 U.S. qt. (3.1L)	25 lb. (11kg)	0.57 ft^3 (0.016m^3)
50 lb. (22.7kg)	Max.(80%)	3.25 U.S. qt. (3.1L)	40 lb. (18kg)	0.66 ft^3 (0.019m^3)

Pre-wet mixer for first batch and allow to drain. Carefully measure 3.25 U.S. qt. (3.1L) of potable mixing water per bag and pour into mixer. Start mixer and slowly add Fast Patch 928. Mix for two to three minutes until a uniform lump-free consistency is obtained.

Applications requiring extension (see "Patch Thickness Limitations" above) must use clean, well-graded, rounded, 3/8 in. (10mm) maximum size pea gravel. The pea gravel should be pre-wet then allowed to drain and dry slightly before use. Add the specified quantity of pea gravel (see "Mixing

Ratios" above) to the mixer only after the Fast Patch 928 and water are well mixed. Continue mixing until the pea gravel blends in evenly. Do not add additional water when using pea gravel or after initial mixing (Do not retemper).

Placement/Consolidation/Finishing: After mixing, Fast Patch 928 should be placed without delay, then quickly consolidated by tamping or vibration. The surface can be finished immediately after strike-off or it can be left slightly above the surrounding concrete and later shaved down and textured with the sharp edge of a trowel after initial set occurs.

Mix only the amount of material that can be placed, consolidated and finished within the available working time of approximately 10 minutes @ 70°F (21°C). Large jobs require adequate personnel and equipment to permit mixing, placing, and finishing operations to occur simultaneously and without interruption, in order to avoid cold joints.

Temperature Considerations: Fast Patch 928 is useable over a temperature range of 40°F (4°C) to 95°F (35°C). Setting and strength development will be retarded by cold temperature and accelerated by hot temperature. Store materials in a dry shaded area.

Curing: During mild weather conditions, i.e. calm, 80°F (27°C) maximum temperature, when rapid turnaround is necessary, damp or membrane curing may not be required. If hot over 80°F (27°C), dry, or windy conditions exist, or when schedule permits, apply an ASTM C 309 membrane forming curing compound, such as Burke Spartan Cote WB or Burke Aqua Resin at the recommended coverage rate. Alternatively, cure with polyethylene sheeting over wet burlap for as long as possible up to 3 days. Protect patched area from vibration or loading until desired strength is achieved.

LIMITATIONS

Do not add sand, cement or any admixtures. Do not place in lifts. Do not use for patching asphalt or latex modified concretes.

CAUTION

Avoid breathing dust particles. Burke recommends use of appropriate safety equipment (i.e. gloves, dust masks, eye protection) when working with this product. Skin may be sensitive to cement. Avoid contact with eyes or prolonged contact with skin. **If eye contact occurs, flush eyes immediately and repeatedly with fresh water,** then seek medical attention without delay. Wash exposed skin areas with soap and water. **KEEP OUT OF THE REACH OF CHILDREN**

WARRANTY

Burke products will perform according to specifications only if directions are followed. Burke is not responsible for improper use, application, or storage of its products or for use of its products in unsafe weather or with unsafe engineering or working conditions. Burke products are supplied subject to Burke's standard terms and conditions of sale or rental, which limit Burke's responsibility for the product. Any warranty of the product is limited to Burke's or the manufacturer's standard warranty unless otherwise specifically provided by Burke in writing.

Hazardous Components

Portland Cement
Calcium Aluminate Cement
Silica, Crystalline Quartz
Lithium Carbonate

APPENDIX B – LABORATORY RESEARCH DATA

INDEX OF BATCHES

Batch Number	Description
1	Ashgrove Type III, 600 pcy, w/c = 0.35
2	Lonestar Type III, 600 pcy, w/c = 0.35
3	Holnam Type I , 600 pcy, w/c = 0.35
4	Holnam Type I, 700 pcy, w/c = 0.30
5	Lonestar Type III, 700 pcy, w/c = 0.30
6	Lonestar Type III, 700 pcy, w/c = 0.30
7	Holnam Type I, 700 pcy, w/c = 0.30
8	Holnam Type I , 700 pcy, w/c = 0.30, Freeze/Thaw
9	Lonestar Type III, 700 pcy, w/c = 0.30, Freeze/Thaw
10	Holnam Type I, 700 pcy, w/c = 0.30, Slump Loss
11	Lonestar Type III, 700 pcy, w/c = 0.30, Slump Loss
12	Holnam Type I/HAC 2% Blend, 600 pcy, w/c = 0.35
13	Holnam Type I/HAC5% Blend, 600 pcy, w/c = 0.35
14	Holnam Type I/HAC 3% Blend, 600 pcy, w/c = 0.35
15	Lonestar Type III, 700 pcy, w/c = 0.30, DCI = 384 oz/yd
16	Lonestar Type III, 700 pcy, w/c = 0.30, DCI = 512 oz/yd
17	Lonestar Type III, 700 pcy, w/c = 0.30, DCI = 640 oz/yd
18	Holnam Type III, 600 pcy, w/c = 0.35, SRA - none
19	Holnam Type III, 600 pcy, w/c = 0.35, SRA -Tetragard =192 oz/yd
20	Holnam Type III, 600 pcy, w/c = 0.35, SRA -Eclipse =192 oz/yd
21	Holnam Type III, 600 pcy, w/c = 0.35, SRA -Tetragard =96 oz/yd
22	Holnam Type I, 600 pcy, w/c = 0.33, SRA - Tetragard = 192 oz/yd
23	Holnam Type I, 600 pcy, w/c = 0.33, SRA - Eclipse = 192 oz/yd
24	Lonestar Type III, 700 pcy, w/c = 0.30, Sika Admixtures
25	Lonestar Type III, 700 pcy, w/c = 0.30, Sika Admixtures
26	Lonestar Type III, 700 pcy, w/c = 0.30, Fibers = 0
27	Lonestar Type III, 700 pcy, w/c = 0.30, Fibers = 0.75 lb/yd
28	Lonestar Type III, 700 pcy, w/c = 0.30, Fibers =1.5 lb/yd
29	Lonestar Type III, 700 pcy, w/c = 0.30, Fibers =0.75 lb/yd, Beam
30	Lonestar Type III, 700 pcy, w/c = 0.30, Fibers =1.5 lb/yd, Beams

Batch #1

w/c=	0.35
cement =	600
Type =	III

Sand % water =	1.7
Rock % water =	0.29

Mixture Proportions for One Cubic Yard	
Cement Ashgrove Type III	600 lb
Coarse Aggregate, #67	1777 lb
Fine Aggregate, Dover Sand	1435 lb
Water	164 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	6"
Unit Wt.:	151.8
Air Content:	n/a
Conc. Temp:	73
Air Temp:	55

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4hrs	6hrs	9hrs	12hrs	1 day	3 day	7 day	28 day
69	115	978	2806	5543	5835	7341	8288
58	137	1023	2787	5554	7773	7364	8533
		1110	2835	5664	7547	7718	8398

Batch #2

w/c=	0.35
cement =	600
Type =	III

Sand % water =	3.5
Rock % water =	0.42

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	600
Coarse Aggregate, #67	1780
Fine Aggregate, Dover Sand	1461
Water	135
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	9"
Unit Wt.:	151.96
Air Content:	n/a
Conc. Temp:	65
Air Temp:	50

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
277	1888	2884	3790	5679	6524	7544	8184
263	1894	2881	3799	5604	6012	7361	8320
	1928	2611	3944	5742	6279	7361	7637

Batch #3

w/c=	0.35
cement =	600
Type =	I

Sand % water =	2.47
Rock % water =	0.6

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I	600 lb
Coarse Aggregate, #67	1783 lb
Fine Aggregate, Dover Sand	1446 lb
Water	147 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	5"
Unit Wt.:	152.04
Air Content:	n/a
Conc. Temp:	72
Air Temp:	55

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
556	2134	3540	5089	8419	10271	10320	12690
438	2087	3289	4763	7725	9801	10912	12452
	2488	3385	5002	8382	97525	10723	12774

Batch #4

w/c=	0.3
cement =	700
Type =	I

Sand % water =	1.63
Rock % water =	0.13

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I	700 lb
Coarse Aggregate, #67	1774 lb
Fine Aggregate, Dover Sand	1349 lb
Water	168 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	7.5"
Unit Wt.:	149.4
Air Content:	n/a
Conc. Temp:	75
Air Temp:	70

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
813	3801	4905	5763	6664	9141	9983	10875
733	3710	4634	5548	6887	9206	9326	10196
	3961	4726	5748	7113	9132	10242	9889

Batch #5

w/c=	0.3
cement =	700
Type =	III

Sand % water =		3.52
Rock % water =		0.47

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb.
Coarse Aggregate, #67	1780 lb.
Fine Aggregate, Dover Sand	1374 lb.
Water	136 lb.
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	9"
Unit Wt.:	149.4
Air Content:	n/a
Conc. Temp:	78
Air Temp:	70

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
327	3337	4328	5284	6377	7906	8473	10875
452	3409	4501	5006	6526	7854	8911	10196
	3561	4372	5217	6468	8037	8549	9889

Batch #6

w/c=	0.3
cement =	700
Type =	III

Sand % water =	2.35
Rock % water =	0.15

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1359 lb
Water	158 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	6.75"
Unit Wt.:	149.4
Air Content:	0.019
Conc. Temp:	90
Air Temp:	80

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
2311	5268	5997	6637	7518	8905	9345	10236
2374	5170	6123	6498	7481	8875	9456	10004
2415	5354	6047	6701	7709	9019	9456	10426

Shrinkage Measurments (10^{-6} in/in)							
6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day	56 day
130	170	190	210	280	360	490	520
90	130	150	270	340	410	540	580
100	150	170	190	250	320	420	450

RCIP Data (Coulombs Passed @ 6 hours)			
Spec. 1	Spec. 2	Spec. 3	Spec. 4
1271	1498	1304	1105

Batch #7

w/c=	0.3
cement =	700
Type =	I

Sand % water =	2.4
Rock % water =	0.43

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I	700 lb
Coarse Aggregate, #67	1780 lb
Fine Aggregate, Dover Sand	1359 lb
Water	152 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	3"
Unit Wt.:	149.2
Air Content:	2.10%
Conc. Temp:	73
Air Temp:	70

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
1848	4525	5874	6593	7723	8823	10446	11232
1796	4618	6115	6476	7513	8469	9978	11426
2004	4725	6036	6628	7624	9102	9457	11270

Shrinkage Measuments (inches)							
6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day	56 day
110	20	130	150	210	250	380	400
120	130	140	170	210	250	380	400
110	130	160	190	240	270	370	390

RCIP Data (Coulombs Passed @ 6 hours)			
Spec.1	Spec. 2	Spec. 3	Spec. 4
835	1047	1096	935

Batch #8

w/c=	0.3
cement =	700
Type =	I

Sand % water =	5.76
Rock % water =	0.13

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I	700 lb
Coarse Aggregate, #67	1774 lb
Fine Aggregate, Dover Sand	1404 lb
Water	109 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	6.25
Unit Wt.:	148.7
Air Content:	2.1
Conc. Temp:	75
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	3753						10236
	3632						9892
	3917						10151

Freeze/Thaw Data		0 Cycles	50 Cycles	300 Cycles
Transverse Frequency (Hz)	1	2542	2478	2183
	2	2472	2463	1863
	3	2520	2575	2142
	4	2470	2528	2435
Longitudinal Frequency (Hz)	1	5611	n/a	n/a
	2	5656	n/a	n/a
	3	5595	n/a	n/a
	4	5625	n/a	n/a
Weight (lb.)	1	17.81	17.32	17.16
	2	17.55	17.63	17.51
	3	18.04	17.01	17.06
	4	17.71	17.52	17.59

Batch #9

w/c=	0.3
cement =	700
Type =	III

Sand % water =		4.06
Rock % water =		0.38

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1779 lb
Fine Aggregate, Dover Sand	1381 lb
Water	130 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	5"
Unit Wt.:	150.1
Air Content:	1.8
Conc. Temp:	80
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	5117						10491
	5328						9805
	5681						10151

Freeze/Thaw Data		0 Cycles	50 Cycles	300 Cycles
Transverse Frequency (Hz)	1	2516	2518	2250
	2	2506	2506	2506
	3	2528	2510	2489
	4	2558	2456	2529
Longitudinal Frequency (Hz)	1	5733	n/a	n/a
	2	5734	n/a	n/a
	3	5722	n/a	n/a
	4	5714	n/a	n/a
Weight (lb.)	1	17.32	17.22	17.16
	2	17.62	17.55	17.55
	3	17.81	17.7	17.69
	4	18.2	18.04	18.02

Batch #10

w/c=	0.3
cement =	700
Type =	I

Sand % water =	1.22
Rock % water =	0.24

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I	700 lb
Coarse Aggregate, #67	1776 lb
Fine Aggregate, Dover Sand	1344 lb
Water	172 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	9.5
Unit Wt.:	n/a
Air Content:	n/a
Conc. Temp:	85
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	3246						10975
	3725						11123
	3108						10774

Slump Loss Test	
Time (min.)	Slump (in.)
0	9.5
5	9
10	7.75
20	5.75
30	2.5

Batch #11

w/c=	0.3
cement =	700
Type =	III

Sand % water =	1.22
Rock % water =	0.24

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1776 lb
Fine Aggregate, Dover Sand	1344 lb
Water	172 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	6.75
Unit Wt.:	n/a
Air Content:	n/a
Conc. Temp:	85
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	3744						9765
	3963						10013
	3421						10429

Slump Loss Test	
Time (min.)	Slump (in.)
0	6.75
5	4.5
10	2.75
15	2.5
20	2.5
25	2.5
30	1.75

Batch #12

w/c=	0.35
cement =	600
Type =	2% Blend

Sand % water =	3.05
Rock % water =	0.25

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I/HAC	600 lb
Coarse Aggregate, #67	1777 lb
Fine Aggregate, Dover Sand	1454 lb
Water	144 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

HAC = High Aluminate Cement, Provided By Burke Fastpatch

Fresh Concrete Properties	
Slump:	8"
Unit Wt.:	147
Air Content:	n/a
Conc. Temp:	78
Air Temp:	70

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
1457	2861	3987	4945	5839	7727	8395	9744
1171	3127	4218	5076	5694	7919	8500	9836
1346	3040	4134	5005	5995	7890	7899	10070

Batch #13

w/c=	0.35
cement =	600
Type =	5% Blend

Sand % water =	1.64
Rock % water =	0.17

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I/HAC	600 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1434 lb
Water	166 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

HAC = High Aluminate Cement,
Provided By Burke Fastpatch

Fresh Concrete Properties	
Slump:	7"
Unit Wt.:	146.8
Air Content:	n/a
Conc. Temp:	78
Air Temp:	70

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
363	1255	2248	3196	4136	6250	6846	8007
396	1375	2376	3214	4220	5247	6696	7943
377	1394	2320	3098	4321	5619	6796	7876

Batch #14

w/c=	0.35
cement =	600
Type =	3% Blend

Sand % water =	2.39
Rock % water =	0.17

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I/HAC	600 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1445 lb
Water	156 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

HAC = High Aluminate Cement,
Provided By Burke Fastpatch

Fresh Concrete Properties	
Slump:	7"
Unit Wt.:	147
Air Content:	n/a
Conc. Temp:	83
Air Temp:	75

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
1300	2480	3378	4253	5327	7043	7834	9103
1224	2565	3401	3953	5095	7286	7767	9002
1533	2868	3304	4216	5233	7066	7789	9089

Batch #15

w/c=	0.35
cement =	700
Type =	III

Sand % water =	0.24
Rock % water =	0.17

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1776 lb
Fine Aggregate, Dover Sand	1397 lb
Water	208 lb
ADVA (HRWR)	90 oz
DCI (Accel)	384 oz

Fresh Concrete Properties	
Slump:	0.5
Unit Wt.:	147
Air Content:	n/a
Conc. Temp:	85
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	100			2930		8499	9273
				2517		8194	9864
						8033	9114

Batch #16

w/c=	0.35
cement =	700
Type =	III

Sand % water =	0.244
Rock % water =	0.14

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1375 lb
Water	201lb
ADVA (HRWR)	90 oz
DCI (Accel)	512 oz

Fresh Concrete Properties	
Slump:	2"
Unit Wt.:	149.1
Air Content:	2%
Conc. Temp:	77
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	1067	4621	7450	8277		9016	10038
	1498	4815	7378	8123		8992	10075
	1779	4309	7293	8301		9138	9821

Batch #17

w/c=	0.35
cement =	700
Type =	III

Sand % water =	0.244
Rock % water =	0.14

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1353 lb
Water	194 lb
ADVA (HRWR)	90 oz
DCI (Accel)	640 oz

Fresh Concrete Properties	
Slump:	2.25
Unit Wt.:	148.4
Air Content:	2%
Conc. Temp:	85
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	2879	5318	7016	8825		9143	9776
	2753	5817	6987	8016		8082	10377
	2781	5496	7533	8694		9188	10199

Batch #18

w/c=	0.35
cement =	600
Type =	III

Sand % water =	1.4
Rock % water =	0.09

Mixture Proportions for One Cubic Yard	
Cement Holnam Type III	600
Coarse Aggregate, #67	1774 lb
Fine Aggregate, Dover Sand	1431 lb
Water	172 lb
SRA	none
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	3"
Unit Wt.:	149
Air Content:	n/a
Conc. Temp:	96
Air Temp:	85

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
4697	5919	7871		9102	10286	10560	11402
4806	5949	7821		8766	10852	10545	11396
	5840	7954		8758	10123	9832	11333

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	0.0885	0.087		0.0865	0.086	0.0858	0.0854
	0.0975	0.0962		0.0958	0.0953	0.0951	0.0947
	0.0888	0.0871		0.0868	0.0863	0.086	0.0856

Batch #19

w/c=	0.35
cement =	600
Type =	III

Sand % water =	1.69
Rock % water =	0.24

Mixture Proportions for One Cubic Yard	
Cement Holnam Type III	600 lb
Coarse Aggregate, #67	1776 lb
Fine Aggregate, Dover Sand	1435 lb
Water	165 lb
Tetragard (SRA)	192 oz
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	9.5"
Unit Wt.:	148.7
Air Content:	n/a
Conc. Temp:	79
Air Temp:	66

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
1417	3262	4932	5287	6283	8385	9471	11185
1368	3493	4649	5400	6848	8067	8813	11183
	3370	4775	5339	6557	9010	9973	10933

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	0.1218	0.1211	0.121	0.1208	0.1206	0.1205	0.1196
	0.1041	0.1034	0.1032	0.103	0.1028	0.1026	0.1018
	0.135	0.1342	0.1341	0.1339	0.1338	0.1337	0.1327

Batch #20

w/c=	0.35
cement =	600
Type =	III

Sand % water =	2.3
Rock % water =	0.4

Mixture Proportions for One Cubic Yard	
Cement Holnam Type III	600 lb
Coarse Aggregate, #67	1779 lb
Fine Aggregate, Dover Sand	1444 lb
Water	153 lb
Eclipse (SRA)	192 oz
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	4"
Unit Wt.:	149.2
Air Content:	n/a
Conc. Temp:	85
Air Temp:	82

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
131	870	2618		4479	6354	6811	6778
118	862	2909		4196	6521	7377	7667
				4910	6444	7084	6599

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
		0.1094		0.1089	0.1083	0.1084	0.1083
		0.1031		0.1032	0.1022	0.1024	0.1022
		0.0881		0.0872	0.0867	0.0869	0.0867

Batch #21

w/c=	0.35
cement =	600
Type =	III

Sand % water =	1.19
Rock % water =	0.15

Mixture Proportions for One Cubic Yard	
Cement Holnam Type III	600 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1428 lb
Water	174 lb
Tetragard (SRA)	96 oz
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	3"
Unit Wt.:	149.4
Air Content:	n/a
Conc. Temp:	91
Air Temp:	85

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
1696	3970	5302		6665	8551	10274	10175
1534	4008	5036		7776	8864	9793	10304
1976	4093	4794		6755	8858	9712	10251

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	0.1021	0.101		0.1006	0.1003	0.1001	0.0992
	0.1074	0.1065		0.1062	0.1061	0.1054	0.1048
	0.0991	0.0979		0.0976	0.0975	0.0971	0.0963

Batch #22

w/c=	0.33
cement =	600
Type =	I

Sand % water =	1.66
Rock % water =	0.2

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I	600 lb
Coarse Aggregate, #67	1776 lb
Fine Aggregate, Dover Sand	1467 lb
Water	154 lb
Tetragard (SRA)	192 oz
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	7"
Unit Wt.:	149.5
Air Content:	n/a
Conc. Temp:	82
Air Temp:	79

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	1333		2996	4163	5839	7980	8470
	1455		3024	4306	6203	831	8701
	1394		3474	4233	6082	7649	9177

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	0.1021		0.0981	0.0977	0.097	0.0967	0.0962
	0.1074		0.0972	0.0968	0.0962	0.0958	0.0955
	0.0991		0.0966	0.0962	0.0956	0.0951	0.0948

Batch #23

w/c=	0.33
cement =	600
Type =	I

Sand % water =	2.43
Rock % water =	0.26

Mixture Proportions for One Cubic Yard	
Cement Holnam Type I	600 lb
Coarse Aggregate, #67	1777 lb
Fine Aggregate, Dover Sand	1478 lb
Water	141
Eclipse (SRA)	192 oz
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	4"
Unit Wt.:	149.4
Air Content:	n/a
Conc. Temp:	93
Air Temp:	90

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	1836	2867	3671	4964	6264	7721	8557
	1672	3037	3866	4856	6239	7352	8495
	2010	2821	3420	4881	6324	7374	8857

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	0.1021		0.0851	0.084	0.0837	0.0834	0.0825
	0.1074		0.1082	0.107	0.1068	0.1063	0.1054
	0.0991						

Batch #24

w/c=	0.35
cement =	700
Type =	III

Sand % water =	0.51
Rock % water =	0.12

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1335 lb
Water	184 lb
Sikament (HRWR)	90 oz
Sika Rapid (Accel)	768 oz

Fresh Concrete Properties	
Slump:	none
Unit Wt.:	n/a
Air Content:	n/a
Conc. Temp:	n/a
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	Did Not Mix						

Batch #25

w/c=	0.3
cement =	700
Type =	III

Sand % water =	2
Rock % water =	0.12

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1350 lb
Water	162 lb
Sikament (HRWR)	180 oz
Sika Rapid (Accel)	800 oz

Fresh Concrete Properties	
Slump:	5"
Unit Wt.:	148.9
Air Content:	1.3
Conc. Temp:	78
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	187	728	1576	2938		5826	8654
	365	840	1494	2764		5943	8920
		836	1792	2487		6543	8018

Batch #26

w/c=	0.3
cement =	700
Type =	III

Sand % water =	4.5
Rock % water =	1.04

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1791 lb
Fine Aggregate, Dover Sand	1388 lb
Fibers (Fibermesh)	0
Water	112 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	5"
Unit Wt.:	149.8
Air Content:	2.10%
Conc. Temp:	76
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	3017	5233	6933	8358		10292	9683
	3240	5494	7145	8105		10180	10359
	3145	5117	707	8143		10277	10640

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day

Splitting Cylinder (lb)		MOR			Slant Shear (psi)	
1 Day	28 Day	Depth (in)	Width (in)	Load (lb)	1 Day	28 Day
32085	37455	6.355	6.036	9870	94376	94763
34320	42240	6.3575	63.018		87241	90017
43440	39600	6.375	6.028		88490	89149
		6.137	6.004	9315		
		6.173	6.033			
		6.155	6.073			

Batch #27

w/c=	0.3
cement =	700
Type =	III

Sand % water =	4.5
Rock % water =	1.04

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1791 lb
Fine Aggregate, Dover Sand	1388 lb
Fibers (Fibermesh)	0.75
Water	112 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	4.5
Unit Wt.:	150.3
Air Content:	1.80%
Conc. Temp:	76
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
193	2529	4967	6937	8196		9500	9443
232	2367	5276	7006	7889		10704	9728
	2736	5188	7238	8920		9863	10080

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	0.1477	0.147	0.1468	0.1462		0.1446	0.1439
	0.2421	0.2414	0.2412	0.2406		0.2389	0.2382

Splitting Cylinder (lb)		MOR			Slant Shear (psi)	
1 Day	28 Day	Depth (in)	Width (in)	Load (lb)	1 Day	28 Day
31200	31875	6.1	6.5	11385	88364	90763
33900	36285	5.915	6.25		87249	91243
30600	35805	5.9	5.916		80736	89246
		6.117	6.132	10245		
		6.16	5.993			
		6.16	6.01			

Batch #28

w/c=	0.3
cement =	700
Type =	III

Sand % water =	4.5
Rock % water =	1.04

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1791 lb
Fine Aggregate, Dover Sand	1388 lb
Fibers (Fibermesh)	1.50
Water	112 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	4"
Unit Wt.:	150.1
Air Content:	1.90%
Conc. Temp:	1.8
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	2822	4438	6013	7200		8292	10449
	2927	4276	6149	7136		9602	10519
		4401	5879	7149		9374	10761

Shrinkage Measurments (inches)							
4 hr	6 hr	9 hr	12 hr	1 day	3 day	7 day	28 day
	0.1577	0.1568	0.1565	0.1557		0.1542	0.1535
	0.0996	0.0988	0.0985	0.0976		0.0961	0.0954

Splitting Cylinder (lb)		MOR		
1 Day	28 Day	Depth (in)	Width (in)	Load (lb)
33495	41295	6.185	6.026	10845
33480	43215	6.08	6.008	
35700	42270	6.058	6.039	
		6.166	6.008	11130
		6.242	6.01	
		6.321	6.028	

Slant Shear (psi)	
1 Day	28 Day
92763	95432
94480	90147
94973	87666

Batch #29

w/c=	0.3
cement =	700
Type =	III

Sand % water =	5
Rock % water =	1

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1790 lb
Fine Aggregate, Dover Sand	1394 lb
Fibers (Fibermesh)	0.00
Water	106 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	5"
Unit Wt.:	150.2
Air Content:	n/a
Conc. Temp:	80
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)							
	6 hour	Time of Test				
	3125	10263				
	3423	10017				
	3025	10454				

Horizontal Shear Beams		
Beam Failure Load (kips)	Beam #1	15.7
	Beam #2	21.24
Beam Failure Mode	Beam #1	flexure
	Beam #2	flexure

Beam #1 had 0.4 in^2 of steel reinforcement
Beam #2 had 1.15 in^2 steel reinforcement

Batch #30

w/c=	0.3
cement =	700
Type =	III

Sand % water =	2.259
Rock % water =	0.11

Mixture Proportions for One Cubic Yard	
Cement Lonestar Type III	700 lb
Coarse Aggregate, #67	1775 lb
Fine Aggregate, Dover Sand	1358 lb
Fibers (Fibermesh)	1.50
Water	160 lb
ADVA (HRWR)	90 oz
DCI (Accel)	768 oz

Fresh Concrete Properties	
Slump:	4.25
Unit Wt.:	150.1
Air Content:	n/a
Conc. Temp:	84
Air Temp:	n/a

Hardened Concrete Properties

Compressive Strength test breaks (psi)						
	6 hour	Time of Test				
	3542	10793				
	3648	10436				
	3329	10821				

Horizontal Shear Beams		
Beam Failure Load (kips)	Beam #1	21.02
	Beam #2	18.8
Beam Failure Mode	Beam #1	Hor. Shear
	Beam #2	Hor. Shear

Beam #1 had 1.15 in^2 of steel reinforcement
Beam #2 had 1.15 in^2 steel reinforcement